Supporting local flood risk decision-making using participatory modelling

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Abstract

Flood risk management is increasingly seeking to involve local stakeholders in decision-making, both to harness and benefit from their tacit knowledge and to devolve responsibility for delivering local-scale, individual and community responses.

Current techniques used in flood risk management centre on a techno-scientific approach, which is well-suited to appraising and modelling hazard, but often inaccessible to those without specialist, technical expertise. This leads to participation that is often limited to infrequent consultation periods, keeping local stakeholders at the periphery of the decision-making process. Their absence from the more technical elements of the process can leave local stakeholders struggling to understand how different options have been identified, appraised and/or prioritised. This can in turn lead to dissatisfaction with process outcomes, lack of support for selected options, and foster distrust in expert practitioners.

This thesis explores how participatory modelling techniques could complement current approaches, facilitating the co-production of models with local stakeholders that explore social constructions of risk, and the vulnerability of different receptors. It identifies the qualities that are sought from participation, including the need to remain highly accessible, yet sufficiently robust to capture the complexities encountered when working at the interface of social and physical systems.

Reporting on two UK case studies, it exemplifies the benefits that two popular techniques, Bayesian networks and system dynamics, can deliver at different stages in the flood risk decision-making process. In each case, the effectiveness of the participatory approach is assessed using an evaluative framework that advances current approaches by including an early assessment of context, as well as a detailed exploration of substantive (user-defined goals), and social change outcomes. The holistic nature of the evaluation framework, and its population with practical criteria bespoke to flood risk management, enhance its transferability between different contexts. The thesis finds that participatory modelling techniques support the collating of diffuse tacit knowledge, building of consensus, strengthening of social networks, and the empowerment of local citizens to become volunteer risk managers; provided that process managers are willing to simplify the techniques to maintain accessibility, and be open to different metrics of success.

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Statement on Joint Authorship

Paper 1: *Doing flood risk modelling differently: a framework for stakeholder participation*

Authors: Maskrey S. A., Mount, N. J. and Thorne, C. R.

Maskrey proposed and wrote early versions of this paper, developing the key qualities for assessing different methodological techniques, designing a stakeholder typology, and conducting a review of three participatory techniques. Dr Mount provided critical analysis of the paper at several key junctures, improving the text, both in isolation and in collaboration with Maskrey, as well as providing a review of Sections 3 and 4 from the perspective of a modeller. Professor Thorne provided insight that helped position the paper in contemporary FRM, and reviewed a final draft of the paper. The paper was submitted for publication and received major revisions. It was decided to resubmit after the publication of Paper 2 had provided evidence on the effectiveness of the framework.

Paper 2: *Participatory modelling for stakeholder involvement in the development of flood risk management intervention options*

Authors: Maskrey, S. A., Mount, N. J., Thorne, C. R. and Dryden, I.

Maskrey conducted the action research elements of the research, developing a participatory methodology and conducting six participatory workshops in Hebden Bridge. He further conducted stakeholder analysis/identification, pre- and post-project interviews with stakeholders, and all qualitative analyses. Dr Mount provided guidance with the development of the manuscript for publication, including editing the early sections. Following review, Mount and Maskrey collaborated on an in-depth review of the methodology (especially Section 5.3). Where comments focussing on the mathematical limitations of the technique could not be addressed adequately by Maskrey and Mount, Professor Dryden (University of Nottingham) provided expertise that improved Section 5.3. Professor Thorne reviewed a final draft of the paper. The paper was published in Environmental Modelling and Software.

Paper 3: *Participatory modelling for stakeholder involvement to review community options for the building of flood risk resilience*

Authors: Maskrey, S. A., Mount, N. J. and Thorne, C. R.

Maskrey conducted the participatory elements of the research, planning and running a schedule of five workshops, pre- and post-project interviews and interim model development sessions with stakeholders in Southwell. He further completed both the quantitative (building, developing and testing the system

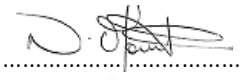
dynamics model), and the qualitative elements of the study (coding and analysing interview transcripts). Dr Mount provided comments on early drafts of the paper, with subsequent edits being made by Maskrey. Professor Thorne read and commented on the conclusions drawn from this paper. The paper has not yet been submitted for publication.

Paper 4: *Towards evaluation criteria in participatory flood risk management*

Authors: Maskrey, S.A., Priest, S., Mount, N. J. and Thorne, C. R.

Maskrey drafted and edited early versions of this paper, including development of the evaluation criteria presented in Sections 4, 5 and 6. After an initial reading, Dr Mount suggested that Dr Priest (Flood Hazard Research Centre, Middlesex University) be consulted for professional advice on evaluation. Dr Priest then provided comments on two versions of the paper, with subsequent edits made by Maskrey. Dr Priest provided additional comments via Skype at a later stage. Further improvements were made to the paper by Maskrey and Mount in collaborative sessions. Professor Thorne read and commented on the conclusions drawn from this paper. The paper has not yet been submitted for publication.

We, the undersigned, accept the above statement as a true reflection of our contribution to the papers contained in this thesis:


..... Dr Nick J. Mount (Supervisor)


..... Professor Colin R. Thorne (Supervisor)


..... Professor Ian Dryden


..... Dr Sally Priest

30 November 2016

Everything we hear is an opinion, not a fact. Everything we see is a perspective, not the truth.

MARCUS AURELIUS

For Nick Mount

With special thanks to:

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Hebden Bridge

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Extended Abstract

1. Introduction

Defining risk, Wisner and colleagues note that, '*The crucial thing about understanding why disasters happen is that it is not only natural events that cause them*' (Wisner *et al.* 2004: 4). In this statement, they characterise risk as an entity that is comprised of both natural and social factors, aspects that are inseparable. Despite recognition of this complexity, traditional flood management (and flood modelling efforts) primarily deals with flood hazard, and the physical phenomena that result in inundation. This technocratic approach, favoured in the UK, is well-suited to managing flood hazard, where models are evaluated against their ability to represent reality, and validated using data collected when events occur (Brown and Damery, 2002; Wheater, 2006).

However, as we increasingly seek an integrated understanding of flood *risk*, we need to extend our currently restricted definitions of exposure and vulnerability that exist to provide an assessment of losses, such that flood risk management becomes a social activity, as much about the receptors at risk as it is about the physical sources and pathways of floodwater. These receptors bring with them an array of social risk constructions and views on how this risk should be managed, and call for model co-production that seeks to build consensus around management options.

The components that constitute risk can be visualised using the source-pathway-receptor model (Holdgate, 1979; HR Wallingford, 2002). The model states that for risk to be present there must be a source of hazard, a receptor susceptible to harm, and a pathway between the source and the receptor (Figure 1.1).

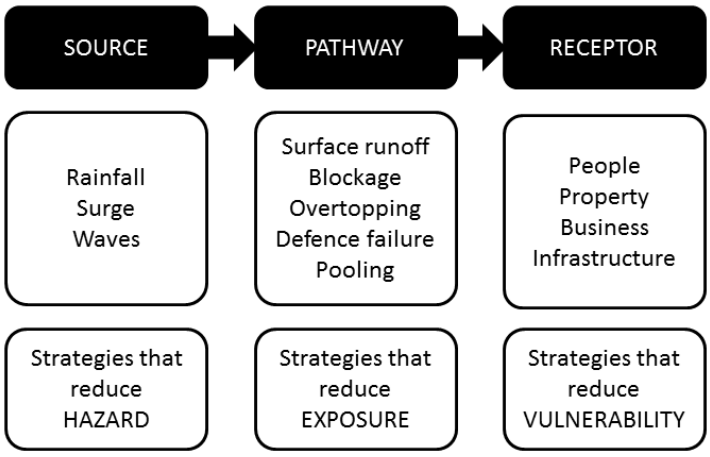


Figure 1.1: Source-pathway-receptor model

Despite the move towards integrated risk-based flood hazard management in the UK, interventions primarily focus on managing the source of the hazard and disrupting the pathways that result in exposure (Sayers *et al.* 2002a; 2002b; 2003; Evans *et al.* 2004). Here we define exposure as a combination of the geographical location of a receptor, and the characteristics of that location that exacerbate or reduce the impact of a hazard (Kazmierczak and Cavan, 2011). This focus on hazard was clearly demonstrated in the case of the Somerset Levels, an area of low-lying agricultural land in SW England that was flooded in the winter of 2013/14. Despite a lack of clear scientific evidence over its effectiveness, the UK government funded a series of drain clearance programmes designed to maximise carrying capacity, and thus disconnect flood pathways (Haughton *et al.* 2015; Fitzpatrick, 2014)

However, the severity of risk depends not only on the nature of the hazard and the physical characteristics of the environment defining the exposure, but also on the level of vulnerability of receptors (Cutter *et al.* 2003; Lindley *et al.* 2006). Here we define vulnerability as the extent to which receptors are susceptible to harm from, or are unable to cope with, a hazard (Kazmierczak and Cavan, 2011).

The appreciation that humans are not equally exposed to (or able to recover from) hazards is crucial. Social processes and inequalities determine who is at greatest risk from flooding: where they live and work; and the level of hazard protection, preparedness, information, wealth and health they are afforded. Integrated flood risk management requires a broadening of the working definition of vulnerability, improved mapping of its spatial variability, and greater understanding of the social, economic and political processes that influence how different people are exposed to hazards in different ways and with different severities.

Understanding and managing vulnerability is quite different to dealing with flood hazard by attempts to control nature or enhance emergency preparedness (Wisner *et al.* 2004), and has been seen as 'irrelevant to science … [or] too difficult to get involved in' (Cannon, 2000: 48). This has arguably led to the restricted construction of vulnerability that exists in flood risk management. Contemporary studies frame vulnerability according to the notion of 'capacity': the ability of a community or individual to resist the harmful effects of a hazard and/or recover more easily (Anderson and Woodrow, 1998; Eade, 1998; IRFC, 1999; Wisner, 2003). Building this capacity to prepare for, cope in, and recover quickly from, flood events should be a primary goal of local flood risk management.

If flood risk management is to move beyond building structural defences and providing emergency response towards more integrated models that address prevention, preparedness and recovery it must manage the whole flooding system, including the complex dependencies, relationships and exchanges that exist at the interface between physical and social systems. Achieving this level of integration

involves overcoming several challenges that are specific to flood risk (Table 1) (for a detailed description of the challenges see Sayers *et al.* 2002b).

Table 1.1: Challenges in flood risk management (after Sayers *et al.* 2002b)

No.	Challenge	Description
1	Loading is variable	The natural drivers of the system (e.g. rainfall, storm surges) are not forecastable beyond a few days into the future. Little or no data may exist on rare events that interventions are designed to manage.
2	Impact is a function of load and response	The severity of flooding is governed by a combination of the load placed on the system and the vulnerability of receptors.
3	Intervention response is complex and uncertain	Interventions, including structural defences, will have complex and uncertain responses to loading. This is particularly true of defence breaching.
4	Spatial interactions are important	It widely recognised that flood defences in one location may exacerbate flood risk downstream. Some of these processes, such as increased erosion downstream of flood defence structures, operate over long time scales and may exhibit unexpected behaviour.
5	Temporal interactions are important	Flood risk systems are dynamic over a number of different timescales. This extends to include geomorphological, ecological and climatological changes, which may be short or long-term. Social and economic changes will further influence the vulnerability of receptors, and therefore the severity and spatial distribution of impacts.
6	Rivers are valued in different ways by stakeholders	The different pressures placed on rivers and floodplains result in severe difficulties in trying to establish 'acceptable' risks from flooding. The needs and priorities of stakeholders will vary by context, and flood risk management needs to respond to this.

Inherent in meeting a number of these challenges, specifically challenges 2, 3, 5 and 6, is the requirement to better understand how receptors are impacted by flooding, and model the feedbacks between sources, pathways and receptors. This knowledge of flood consequences, vulnerability and exposure is tacitly held by those individuals that have interacted with a system over several years: observing the sources, pathways and receptors of floodwater during events of different frequencies. Collaborating with local stakeholders, listening to and taking into account their situated knowledge (Haughton *et al.* 2015), and structuring that knowledge in such a way that it can usefully complement traditional approaches to flood risk management, are essential objectives for meeting these challenges.

Despite efforts by the Environment Agency and others to move towards a more integrated approach which considers the role of local stakeholders (Orr *et al.* 2007), participation in local flood risk management consists largely, and sometimes exclusively, of consultation – whereby local stakeholders are presumed to lack the required knowledge and understanding to take a more active and directive role in the management of flood risk (Jasanoff, 2003). More active participatory processes that involve knowledge sharing and co-production are required, that offer opportunities for collaboration and capacity-building (Figure 1.2).

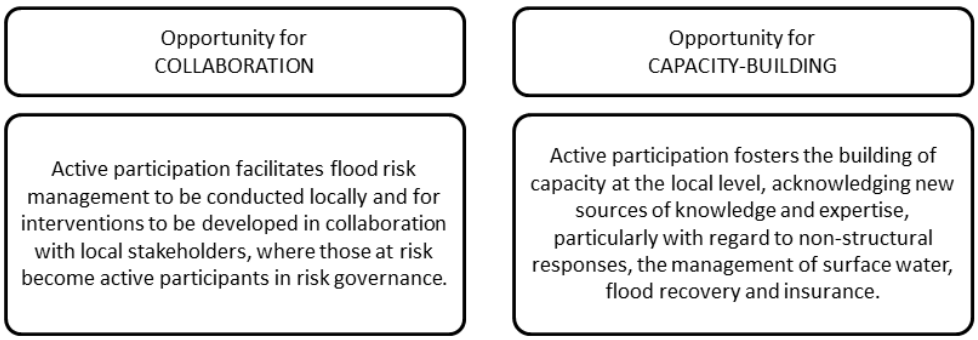


Figure 1.2: Key opportunities for active participation in flood risk management

First, participatory processes can act as fora for sharing and generating information about the different sources of hazard, as well as the exposure and vulnerability of different receptors. This is particularly important in understanding how vulnerability affects flood impact (Challenge 2). With responsibility for flood risk being shared with an increasing number of local stakeholders (including the general public) participatory activities offer opportunities to facilitate collaboration between these groups. In flood risk management, where different stakeholders perceive and construct risk in different ways (Challenge 6), participation can offer a safe space in which views and opinions can be publicly aired and from which interventions arise as the result of consensus (or compromise) between stakeholders.

Second, active participation can signpost participants to sources of context-specific scientific knowledge, practical support and advice; such that the community can independently develop a plan that formalises the role it can play in local flood risk reduction. With the devolution of flood risk responsibilities to the local level comes an increasing emphasis on members of the public and local community groups to take a more active and directive role in managing risk. Where the effectiveness of interventions is uncertain in response to loading (Challenge 3), building capacity within the community to adapt to changing and unpredictable conditions, both during and after a flood event, is essential. It is particularly useful, where changing economic conditions, including the reduced levels of funding available for flood defences and their maintenance, affect the vulnerability of receptors (Challenge 5). Such challenges require flood risk management to maximise local interventions, including property level protection, flood insurance and community-level emergency response.

Within the flood risk management decision making process, there are many stages in which stakeholders could be more actively involved. These stages closely resemble the eight-step decision making process designed for supporting decision-making in the face of climate change risk, outlined in the UK Climate Impacts Programme report *Risk, uncertainty and decision making* (Figure 1.3) (Willows and Connell, 2003: 7).

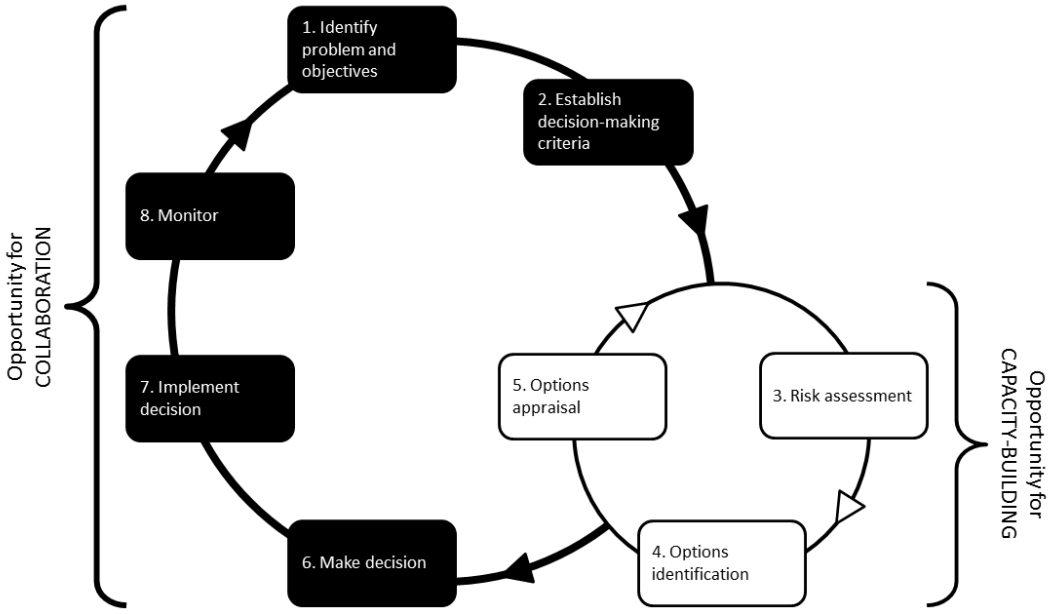


Figure 1.3: Opportunities for collaboration (black boxes) and capacity-building (white boxes) within the flood risk management decision-making process (process stages from Willows and Connell, 2003)

While each of these stages is examined in greater detail in Section 2 (p31), it is important to distinguish between the wider cycle of decision-making and the embedded options identification and assessment cycle (Figure 1.3). Despite some overlap in the opportunities that participation offers the tasks that constitute these cycles, there are differences in the utility of the cycles that make it useful to consider each in isolation. In the wider cycle (black boxes) the tasks undertaken are often non-technical, pertaining to the development of flood risk policy and strategic objectives. These tasks will require the bringing together of a variety of different stakeholders, and are those where participation offers *opportunity for collaboration* (for definition see Figure 1.2). Participation in these steps particularly supports the following challenges facing flood risk management (for full list see Table 1.1):

Challenge 1: loading is variable – flooding events, especially surface water flooding, are highly unpredictable. The data available for flood risk decision making comes primarily from flood events, and therefore is not uniformly available across a catchment. The strategic management of local flood risk therefore requires a variety of different data sources, and knowledge bases, to be utilised.

Challenge 2: impact is a function of loading and response – the impact of flooding is a result of both the loading on the system, and the vulnerability of receptors. Understanding vulnerability when the flood risk problem is being identified (Stage 1) and objectives are being set (Stage 2), will help ensure that the options developed later in the process take account of the spatial variability in vulnerability. Understanding local vulnerability requires drawing on sources of local knowledge and expertise.

Challenge 6: rivers are valued in different ways by stakeholders – the needs and priorities of stakeholders vary according to the local context. Perhaps the greatest benefit of collaboration comes from the bringing together of different stakeholders, who may not normally work together or usually consider their views as conflicting. Building consensus, or at least compromise, between stakeholders increases the likelihood of intervention options being acceptable to, and supported by, the local community.

In the embedded cycle of intervention options identification and appraisal (white boxes), tasks increasingly utilise more advanced mathematical, statistical and GIS methodologies to understand and compare risks at the local level (see Section 2, p35-41). Much of this work, especially that required to produce a flood investigation report following a significant flooding event, is contracted out to environmental consultancies by local authorities that lack in-house technical expertise. Although contracted consultants specialise in the assessment of flood risk, they tend to do so from a flood likelihood perspective, focussing on managing the sources of risk and the pathways that lead to the exposure of receptors (Figure 1.1, p15). Participation in these tasks offers *opportunities for capacity-building*, providing the required skills and experience to enable local stakeholders to engage with

modelling activities, and bringing the management of local flood risk closer to affected communities. It further facilitates the integration of local knowledge on flood risk, which contracted technical specialists generally lack. Participation in these steps supports the following challenges facing flood risk management (for full list see Table 1.1, p18):

Challenge 3: intervention response is complex and uncertain – where structural interventions respond in different and potentially surprising ways to loading, there is the need to invest time and resources in alternative non-structural responses which can be used to manage residual risk, along with the rare events in which structural interventions fail. Non-structural responses, which include *inter alia* emergency planning and preparedness, community response, insurance, and surface water management, require a greater understanding of exposure and vulnerability at the local scale. If local stakeholders (including the general public) are increasingly being asked to take an active role in the management of flood risk, then they will require the capacity to manage these non-structural responses.

Challenges 4 and 5: spatial and temporal interactions are important – the dynamism of flood risk over both spatial (e.g. effect of flood defences on downstream locations) and temporal scales (e.g. impact of changing economic conditions on the maintenance of flood defences) is significant. Understanding how future changes will affect the success of flood risk intervention options is contingent on how well we understand the history of local flood risk. This understanding comes from interaction with a system over many years, and through a range of different flood events, and greatly affects how individuals will behave during and after a flood. Harnessing this understanding to develop robust flood risk interventions requires the participation of local stakeholders in the identification and appraisal of flood risk options. It can further build capacity within members of the community to take actions and exhibit behaviours that minimise damage and champion recovery in the event of flooding.

To facilitate the move from consulting local stakeholders about flood risk, to preparing them for an active role in its governance, participation needs to provide opportunities for discussion about local perceptions of risk, and the co-production of pragmatic intervention options grounded in the community's ability to react to, and cope in, a flood event. It should allow a clearer and more holistic picture to be built up of how the community will respond before, during and after a flooding event. It should promote communication and networking both within and between communities and organisations, such that the costs of adopting protective responses are minimised and individual perceived self-efficacy is increased.

1.1 Research questions and thesis objectives

This thesis addresses four research questions (RQs), which are linked to three objectives (Figure 1.4, p25). Table 1.2 (p26) further supports the reader by synthesising key tasks, methodologies and deliverables for each research question, and indicating where in the thesis each of these are evidenced.

RQ1 asks what flood risk management is seeking from participation. In the thesis, RQ1 is achieved by exploring the current approach to flood risk management in England and Wales, identifying the different stages in the decision-making process, and reviewing the opportunities for participation at each stage. By understanding the unique set of challenges that flood risk management faces (Table 1.1, p18), participation is framed as a practical means of managing the multitude of ways in which flood risk can be social constructed. By bringing together the range of views that are held by local stakeholders, and co-producing a collective view of the problem and its potential solutions, participation offers a route to build consensus and identify preferred solutions. Throughout this thesis, participation is viewed as offering two areas of opportunity for flood risk management: collaboration and capacity building.

RQ2 asks what participation can deliver. This RQ is achieved by reviewing the reasons underlying the move towards a civic approach to participation, in which the previous emphasis placed on technical and scientific knowledge is redistributed such that it extends to the situated knowledge of local stakeholders. Through an investigation of this shift, the potential benefits of participation are identified. A key benefit for flood risk management is the potential to deliver models that take into account and attempt to quantify flood consequences. In Paper 1, the benefits of participation are centred on two key challenges that arise from involving stakeholders in flood risk management, namely accessibility (ensuring stakeholders with little or no technical expertise can participate) and complexity (having techniques that are capable of representing the complex and interconnected physical and social elements of the flood risk system). These challenges offer up five qualities of participation (accessibility, transparency, adaptability, evaluation and holism), which provide the basis for reviewing three popular participatory modelling techniques.

RQ3 is an extension of RQ2 and asks what different participatory modelling techniques can offer at different stages in the flood risk management decision-making process. To understand the flood risk management decision-making framework in the UK, a similar eight-stage risk management framework is borrowed from the UK Climate Impacts Programme report *Risk, uncertainty and decision making* (Figure 1.3, p20) (Willows and Connell, 2003: 7). It is argued that active participation can support flood risk management at each of the stages in the process, although the nature of that participation will vary greatly.

The limited number of papers published on the use of participatory modelling techniques in flood risk management calls for a case study methodology, which partners with two UK communities to exemplify and assess two popular techniques. The first of these uses a Bayesian network model to support risk assessment and options identification in Hebden Bridge, West Yorkshire and is reported in Paper 2; while the second uses elements of system dynamics to support decision implementation in Southwell, Nottinghamshire and is reported in Paper 3. These two communities are at different stages of the decision-making cycle.

RQ4 asks how the effectiveness of participatory processes should be evaluated. Effectiveness is herein framed in terms of both its dimensions and its determinants (after Young, 1994). The thesis goes on to present a holistic evaluation framework in Paper 4, which improves upon previous evaluation frameworks that focus primarily on the process; including a preliminary assessment of context, as well as a subsequent focus on substantive outcomes and longer-term social outcomes. Practical criteria are provided for all evaluation elements, which are specific to the management of flood risk, yet transferable between contexts.

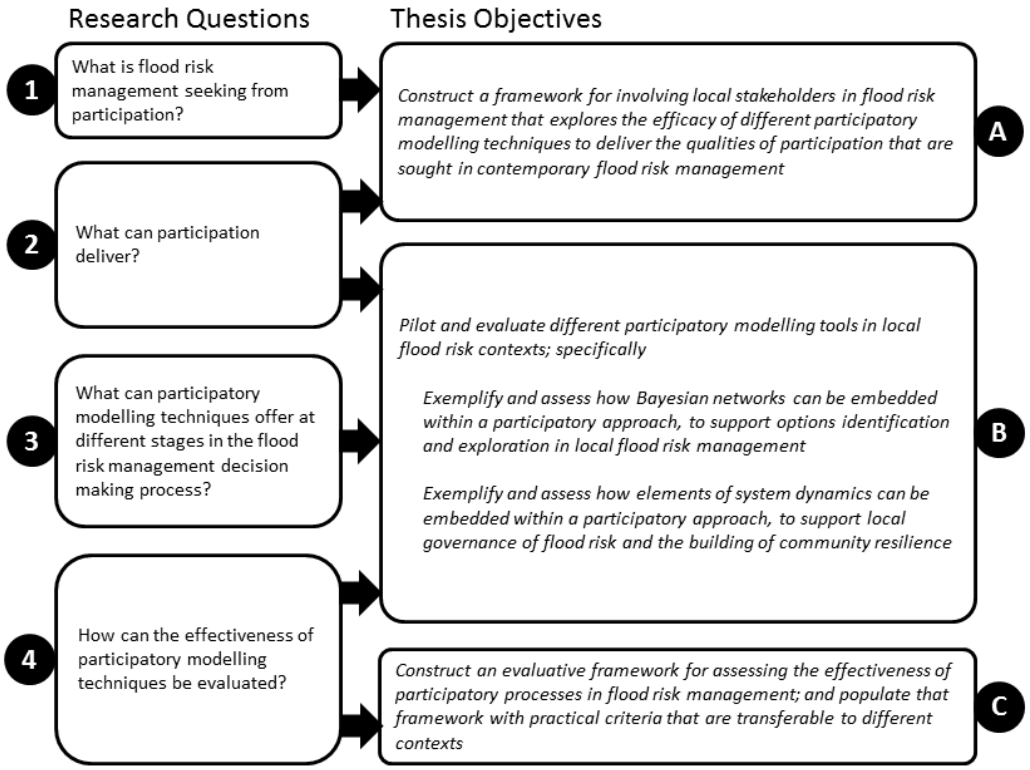


Figure 1.4: Research questions and thesis objectives

Table 1.2: Key tasks, methodologies and deliverables

ID	Key task	Methodology	Deliverable/s
1A	(i) Identify and explore the different stages in the flood risk management decision-making process	Review existing risk management frameworks. Desk study of current UK practice, and subsequent organisation of practices into framework stages.	8-stage **decision-making framework**, adapted from Willows and Connell (2003) (Figure 1.3, p20; p31-46)
	(ii) Understand the challenges facing flood risk management	Literature review of papers on flood risk management in UK, with a focus on integrated management and stakeholder involvement.	Summary table of challenges (Table 1.1, p18)
	(iii) Identify the opportunities participation provides to support the meeting of these challenges	Synthesis of findings in tasks 1A(i) and 1A(ii). Mapping of challenges onto the stages of the decision-making process.	Framing of opportunities into those for collaboration and those for capacity-building (Figure 1.2, p19; pIV—2-IV—5). Summary table bringing together tasks in 1A (Table 2.3, p44).
2A	(i) Identify potential benefits of participation	Literature review of the normative and pragmatic claims made for participation.	Five **qualities of participation** against which different tools can be assessed (Table 5.1, p57)
	(ii) Develop a transferable participatory approach, into which different tools can be embedded	Literature review of existing modelling frameworks and adaptation of Jakeman *et al.* (2006) to meet the needs of Objective B.	**Three-stage participatory approach**, consisting of problem scoping, model co-production, and model testing/evaluation (pI—8)
2B	(i) Review of popular tools available to support participatory modelling	Literature review of three popular participatory modelling tools (Bayesian networks, system dynamics and fuzzy cognitive mapping), and subsequent evaluation of tools based on their ability to deliver the five qualities identified in 2A(i)	**Review of participatory modelling tools**, with qualities compared using star diagrams (pI—14-I—26). Further discussion focusses on accessibility and complexity challenges identified earlier in Paper 1 (pI—2).

[Table continues on next page]

3B	Hebden Bridge Case Study (i) Identification of case study site, including local stakeholder identification and analysis.	Comparison and ranking of potential case study locations against predefined criteria. Stakeholder identification using referral sampling and preliminary interviews with gatekeepers.	Selection of Hebden Bridge, West Yorkshire (pII—5-II—10). Identification of 40 local stakeholders representing 14 organisations (pII—13).
	(ii) Co-production of Bayesian network to represent flood risk system through its cause-effect relationships.	Six evening (2 hr) participatory workshops over a nine month period (2013-14). Use of Cain's (2001) methodology to structure modelling tasks (e.g. eliciting conditional probability tables) (pII—17-II—25).	**Bayesian network model** to represent conceptual physical and social flood risk system in Hebden Bridge (pII—21)
	Southwell Case Study (iv) Identification of case study site, including local stakeholder identification and analysis.	Partnership with Southwell Flood Forum (SFF). Identification of stakeholders through referral sampling, using SFF as primary gatekeeper. Stakeholder analysis using typology modified after Mitchell *et al.* (1997) (pIII—12).	Selection of Southwell, Nottinghamshire as second case study site (pIII—6-III—11). Identification of 35 local stakeholders representing 10 organisations (pIII—13).
	(v) Co-production of system dynamics model to represent the flood system through its cause-effect relationships.	Five evening (2 hour) workshops over a six month period (2015), with interspersed model development meetings. Use of system dynamics principles to frame modelling tasks. Scenario analysis (pIII—26-III—31) using four socio-economic futures.	**Set of eight models, incorporating elements of system dynamics,** and showing how participants perceive risk to change over time as a result of floodwater depth (for example see pIII—29).

[Table continues on next page]

4B	(i) Evaluation of Hebden Bridge case study	Semi-structured post-project interviews held with participants attending at least two workshops. Coding of interview transcript using criteria developed in 4C(i).	Holistic evaluation of process, context and outcomes (pII—30), presented with key findings, discussion and summary figures showing a breakdown by participant group (pII—30-II—39).
	(ii) Evaluation of Southwell case study	As for 4B(i) above	As for 4B(i) above (pIII—31-III—39).
4C	(i) Development of an evaluation framework	Literature review of evaluation of participatory processes, with a particular focus on defining effectiveness and identifying the different elements of participation that form a holistic evaluation.	Discussion on the dimensions and determinants of effectiveness (after Young, 1994) (pIV—5-IV—8). Holistic evaluative framework consisting of four elements (pIV—7).
	(ii) Populating evaluation framework with practical (and transferable) criteria	Theory-based approach (for context, process and social outcome criteria), deriving criteria from literature review and applying them universally to participatory contexts. User-based approach (for substantive outcome criteria), where criteria are co-produced with the end user/s of tangible process outcomes.	Practical evaluation criteria, organised by evaluation element (pIV—8-IV—23).

1.2 Contribution to knowledge

The thesis aims to make the following contributions to knowledge:

1. A theoretical **participation framework** for the critical review of participatory techniques, which assesses their ability to deliver the benefits sought by involving local stakeholders in contemporary flood risk management.

2. The **detailed reporting of two case study examples** where participatory modelling techniques have been used to support the involvement of local stakeholders in flood risk management; and pilot both the participation framework (to select an appropriate technique) and the evaluation framework (to assess the effectiveness of the chosen technique).

3. An **evaluative framework**, populated with practical criteria, for the holistic evaluation of participatory processes, taking into account the context, process design, substantive outcomes (achievement of user goals) and social outcomes.

1.3 Thesis structure

The thesis is organised into four papers, with the following summary locating each of these papers according to the research questions (RQs) and objectives outlined in Figure 1.4 (p25) and Table 1.2 (p26). Paper I presents a transferable participatory approach, into which different participatory modelling tools can subsequently be embedded. It addresses RQ1 and RQ2 through Objective A. Paper II presents the first of two UK case studies, exemplifying and assessing the potential for Bayesian networks to be used to identify flood risk management options in Hebden Bridge, West Yorkshire. It provides evidence to support the claims made for RQ2 and directly addresses RQ3 through Objective B. Paper III presents the second case study, exemplifying and assessing the potential for elements of system dynamics to be used to support the review of community responses for building flood risk resilience in Southwell, Nottinghamshire. It further supports RQ2 and directly addresses RQ3 through Objective B, by focussing on different stages in the flood risk management decision-making framework. Both case study examples are evaluated using the framework and criteria developed in Paper IV. This exemplification of the evaluation framework addresses RQ4 through Objective B. Paper IV further presents the evaluation framework, populated with practical criteria, and specific to the challenges facing flood risk management and the opportunities offered by active participation. It addresses RQ4 through Objective C. Finally, a conclusions chapter (p81-96) presents the conclusions of this thesis, organised by the thesis objective.

The remainder of this extended abstract builds on the framework for decision-making under uncertainty (Figure 1.3, p20), and explores how flood risk management is conducted in England and Wales at each stage in the process (Section 2). Section 3 provides the rationale behind stakeholder participation in flood risk management, focusing on the key drivers behind the move from consultation to more active participation. Section 4 outlines participatory modelling as a potential approach, and introduces two UK case study examples of participatory modelling being used as a means to exemplify the benefits of the approach. The first uses Bayesian networks to support risk assessment and options identification in Hebden Bridge, West Yorkshire while the second uses elements of system dynamics to support decision implementation in Southwell, Nottinghamshire. Section 5 concludes the extended abstract by presenting an overview of, and rationale for, the framework and criteria used to evaluate these cases studies.

2. The process of local flood risk management in England and Wales

Local flood risk management in England and Wales is guided by both national and European legislation. At the national level, the Flood and Water Management Act (2010) provides a framework for the management of flood risk, which in response to the Pitt Review (Pitt, 2008), reinforces the need to manage flood risk holistically and in a sustainable manner. It further clarifies the role and responsibilities of local government bodies, which it designates as Lead Local Flood Authorities (LLFAs). Each LLFA brings together the relevant organisations with a duty to cooperate to produce local strategies for managing local flood risk (from surface water, ground water and ordinary watercourses).

The responsibility for managing fluvial flooding is retained by the Environment Agency, which has powers to carry out maintenance works, improvements and flood defence on main rivers, in addition to acting as a strategic overview body for LLFAs. The Environment Agency provide strategic direction for the management of fluvial flood risk in a series of Catchment Flood Management Plans, which build on the National Flood Risk Assessment by understanding local flood risk mechanisms, and how local risk is changing with respect to climate and land use change. They aim to provide a broad account of the existing flood risk and the measures already in place to manage them.

At the local level, each LLFA facilitates several smaller, multi-agency groups across the region they serve. Membership commonly includes local government officers (often across several departments including flooding, planning and highways), District and Borough council officers, the Environment Agency, water utilities, internal drainage boards and the emergency services (LCC, 2014). These multi-agency groups guide local flood risk management strategies.

The flood risk decision-making process follows a similar path to the framework for supporting decision-making in the face of climate change risk, outlined in the UK Climate Impacts Programme report *Risk, uncertainty and decision making* (Figure 2.1) (Willows and Connell, 2003: 7). The framework consists of eight individual steps that constitute a circular process, allowing the performance of decisions to be reviewed and revisited in light of new information. It further contains an embedded process consisting of the risk assessment, options identification and options appraisal steps (Steps 3-5), allowing potential mitigation options to be iteratively refined and evaluated before making a decision (Step 6).

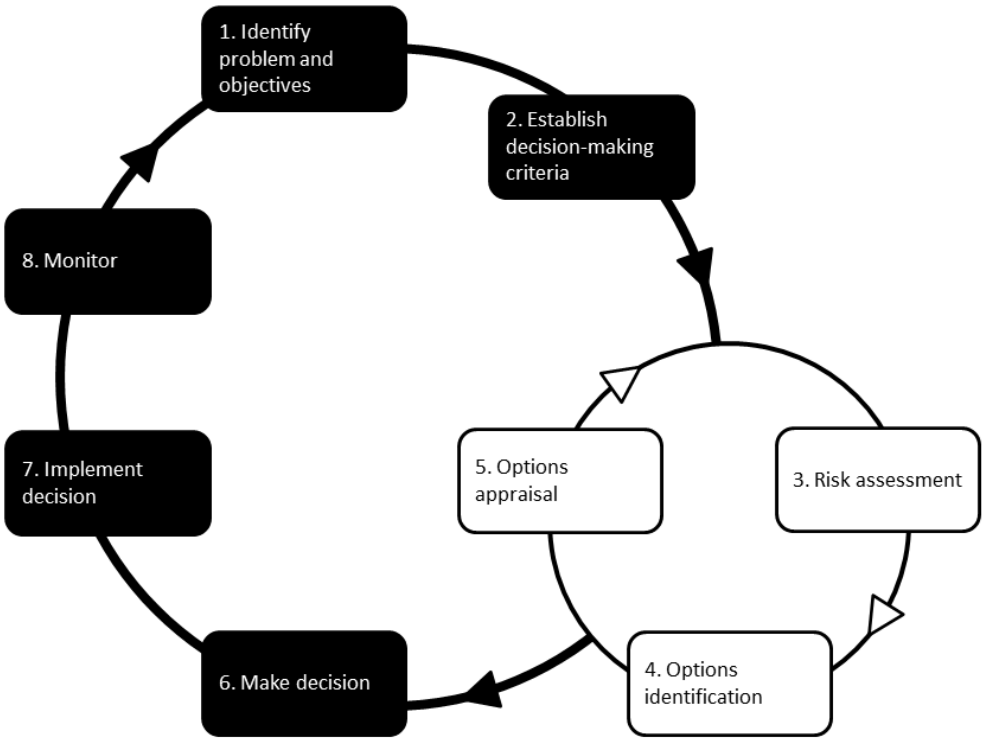


Figure 2.1: Stages in the flood risk management decision-making process (modified after Willows and Connell, 2003)

Unlike climate change adaptation, for which the framework above was conceived, the flood risk management decision process is punctuated by flooding events, which can trigger local decision making processes in response to public and political pressure (Samuels *et al.* 2006). These local processes take a very similar form to the framework in Figure 2.1, but occur on micro spatial and temporal scales, with intervention options often centred on capital projects in place of the policies and programmes that are typical of local flood risk strategy documentation.

In the remainder of this section, the process of local flood risk management is explored by examining the different activities at each stage in the decision-making process. Understanding the process of local flood risk management in this detail reveals what is required from participation at each stage, highlights the potential benefits active stakeholder participation might deliver, and addresses Research Questions 1, 2 and 3 (Section 1.1, p23).

Stage 1: Identify the problem and objectives

The need for a decision can originate from a variety of different sources, including changes to policy or legislation; public concerns; pressure from interest groups or politicians; and new scientific data or technology. Stage 1 involves understanding the reasons why a decision is being made, and the wider

context in which it has arisen, to ensure that the problem is correctly defined and addressed at later stages in the process. It is at this early stage that stakeholders will start to be identified, as it is asked who will benefit or suffer as a result of the problem being addressed or ignored.

In England and Wales, local flood risk decision-making is guided by the strategic objectives laid out in Local Flood Risk Management Strategy documents, which the Flood and Water Management Act (2010) require all LLFAs to produce. These documents provide a framework for LLFAs to co-ordinate flood risk management efforts across the regions they serve, which extends to the management of surface water, ordinary (minor) watercourses and groundwater flooding. For example, the local flood risk management strategy for Leicestershire outlines seven objectives, ranging from adopting a collaborative approach to managing flood risk, to improving resilience through proactive action, activities and education programmes (LCC, 2014). Generally, these objectives closely reflect the National Flood Risk Management Strategy (DEFRA/EA, 2011). They widely promote active participation, and can provide an overview of what flood risk management is seeking from participation at the strategic level (see Research Question 1, p25). Generating these objectives is easily achieved through collaboration with local stakeholders (see example from Hebden Bridge case study, pII—12).

Flooding events, however, can prompt reactive decision-making processes, especially if the event is sufficiently significant to merit the production of a Section 19 Investigation Report (see for example CBMC, 2013a). These local processes can bypass Stages 1 and 2, with the report primarily providing detailed risk assessment based on the new data and information provided by the event.

Stage 2: Establish decision-making criteria

This stage involves taking the broad strategic objectives outlined in Stage 1 and translating them into measurable criteria against which potential options can later be appraised. Options are defined here as combinations of measures taken to reduce flood risk, inclusive of policy changes, long-term programmes and capital works projects. Different stakeholders will inevitably have different priorities and as a result initial criteria often conflict. Recognising areas of conflict at this early stage is essential, in order to identify and develop options that take into account the range of stakeholder views.

Over the last two decades, there has been a notable move towards 'risk-informed' decision-making in the UK (Merz *et al.* 2010). Emphasis is placed on a proportionate response to risk, so that the amount invested is consummate with the projected benefit. In flood risk management, acceptable levels of risk are generally discussed in terms of the number and value of assets (properties, businesses and critical infrastructure) at risk from floods of a given return period. Options to mitigate risk (and the funding available to implement them) are primarily assessed on their ability to protect the assets at risk, either

by removing them from flood-prone areas, or by reducing the frequency by which they are inundated. The choice of criteria and risk assessment endpoints is often determined by the availability of data, scenarios and tools (Willows and Connell, 2003).

The generic decision-making criteria outlined in Local Flood Risk Management Strategy documents (see Stage 1) provide a starting point from which to prioritise areas and communities for investment. Participation at this stage provides an opportunity for collaboration, supporting the development of decision-making criteria that reflect local priorities and concerns (see Research Question 3, p25). An example, taken from Devon County Council's Local Flood Risk Management Strategy, is given in Table 2.1 (DCC, 2014). The impetus is placed on local multi-agency groups, facilitated by the LLFA, to use these criteria to compile their own list of prioritised areas, which are then fed into a regional action plan. Various policy documents support this prioritisation, such as Surface Water Management Plans, Section 19 Flood Investigation Reports (CMBC, 2012a,b), and other detailed flood studies.

Table 2.1: Decision-making criteria used by Devon County Council (DCC, 2014)

Criteria
• Number of properties affected or at high risk in any one community • Frequency of flooding to that community • Depth/severity of flooding experienced or at high risk • Risk to life (particularly the vulnerable such as the elderly, young children, those living with a disability or in areas of deprivation) • Impact on, or high risk of disruption to critical infrastructure • Impact on, or high risk of disruption to businesses and services, especially essential services such as health, education, emergency services • Impact on, or high risk of impact on the environment • Sufficient cost-benefit ratio and robust business case

Lists of criteria such as these give participation a particular role within the decision-making process, define those areas where there is a problem that requires participation, and impose an expert vision of acceptable levels of risk. This gives rise to the potential for the wider roles of participation, as a facilitator of social change, as an enforcer of fair and just decision-making processes, and as a mechanism through which local knowledge is used to define the problem, to be lost. There is certainly scope for participation to play a more central and/or earlier role in the identification of decision-making criteria, a move that may reveal social, socio-demographic and socio-economic priorities that would otherwise go unconsidered.

Stage 3: Risk assessment

At Stage 3, the decision-making process enters an iterative cycle of risk assessment, options identification and options appraisal; stages which are iteratively revisited until a preferred option is identified (Figure 2.1).

The depth of any risk assessment will vary according to, *inter alia*, the nature (is it proactive or reactive) and level (policy change, ongoing programme, capital works, etc.) of the decision, and the available data, funding and resources. Flood risk assessment usually consists of three elements: 1) identifying and defining a set of variables to represent the system and the receptors which may be subject to harm; 2) determining how these variables are interconnected to help understand the risk to the receptors; and 3) using forecasting to help determine how that risk is likely to change under different future scenarios (Willows and Connell, 2003). It follows that risk assessment requires methods that facilitate the active

involvement of local stakeholders, in order that local receptors, and their levels of vulnerability or resilience, are correctly identified and modelled (see Research Question 3, p25).

The source-pathway-receptor conceptual model (Figure 1.1, p15) is widely used in environmental risk management in the UK, and was first applied to describe the flooding system in the Risk Assessment for Strategic Planning (RASP) project (Sayers *et al.* 2002; Sayers and Meadowcroft, 2005). The model states that for a risk to be present there must be a source of the hazard (e.g. heavy rainfall), a receptor (e.g. properties) and a pathway between the source and the receptor (for a worked example see Sayers *et al.* 2002: 40). In flood risk management, special consideration of how sources, pathways and receptors change over defined temporal (i.e. flood event) and spatial (i.e. geographical area) domains is critical.

Generally, risk assessment will start with a broader, qualitative assessment and may (or may not) move on to semi-quantitative and specific quantitative risk assessments at a later stage. A broad, preliminary risk assessment intends to provide an indication as to which risks could significantly influence the final decision. It is at this step that the relevant decision variables are assembled (Merz *et al.* 2010).

In their guidance to Lead Local Flood Authorities, the Environment Agency adopt the four-stage risk management cycle proposed by the European Union Flood Directive (EC, 2007):

1. Preliminary flood risk assessment
2. Identification of flood risk areas
3. Flood hazard and flood risk mapping
4. Flood risk management plans

This four-step risk assessment starts with a broad preliminary flood risk assessment and moves towards a more quantitative representation of risk using flood hazard and flood risk mapping (DEFRA/EA, 2014). In England and Wales, flood hazard is primarily assessed using the Flood Map, produced by the Environment Agency, to show where floods may occur and indicating their likely severity. This Map provides the broad risk assessment required to support LLFAs with the production of Local Flood Risk Management Strategies (*ibid.*). Local assessment using the Flood Map differs from the National Flood Risk Assessment, which includes more detailed information about risk and vulnerability, considering the impact of flood defences and other measures to reduce risk (DEFRA, 2009). Akin to the Willows and Connell (2003) decision-making process (Figure 2.1), risk assessment is an iterative process, with Local Flood Risk Management Strategies reviewed on a six-year cycle (DEFRA/EA, 2014).

Detailed flood risk assessment methods suggested by DEFRA/EA (2014) are organised by the technical competence and skills of the end user (Table 2.2). The language used by DEFRA and the EA suggests a disparity in technical skills and expertise amongst those tasked with flood risk management, and

reinforces the need for participation to provide opportunities for capacity-building in local stakeholder groups (see Research Question 3, p25).

Table 2.2: Methods for flood risk assessment in England and Wales (DEFRA/EA, 2014)

No.	Method	Description	Example/s
Methods that can be used by anyone:			
1	Flood risk indicators	An intersection of national flood outlines with receptor data within a graphical information system (GIS) to calculate flood risk indicators (FRIs).	Simple count of properties or assets within the 1:100 year floodplain
2	Flood risk hotspots	The analysis of flood risk indicators by comparison with a locally generated threshold level, to compare between different areas and identify hotspots.	Designation of low and high risk to areas where 100 and 250 properties (respectively) are located in the 1:100 year flood plain. Mapping these areas to identify hotspots.
3	Prioritising hotspots	Assigning flood risk indicators relative priority scores that reflect local priorities, in order to rank hotspots.	Number of properties at risk is assigned less importance than the age of the residents living in those properties to prioritise areas of high vulnerability.
Methods useful to some:			
4	Locally available hydraulic models	Use of detailed local models to provide outputs that describe the hazard posed by flooding.	
5	Property level depth analysis	Using local 1D and 2D models to provide as estimate of floodwater depth in individual properties.	GIS suggested, with polygons (properties) overlying a floodwater depth layer, with descriptive statistics drawn for each polygon.
6	Calculating damages	Using depth data to estimate damages using well-established depth-damage relationships	Suggests using Multi Coloured Manual (HR Wallingford, 2008)
7	Risk annualisation	Calculating annual average damages using probability-weighted depth grids	
Methods useful to a few:			
8	Probabilistic system performance methods	No methods or tools currently in operational use, references given in report to research methods covering some aspects.	

The risk assessment process is accelerated following significant flooding events, in response to which Lead Local Flood Authorities (LLFAs) are required to publish a 'Section 19' Investigation Report, a statutory requirement under the Flood and Water Management Act (2010). LLFAs determine the thresholds at which they consider an event to be 'significant'. For example, the criteria used by Buckinghamshire County Council include the number of properties flooded, the length of time properties are flooded, the flooding of critical infrastructure, and the closing of transport links for specified lengths of time (BCC, 2013: 43).

A Section 19 report is required to investigate which risk management authorities have the relevant risk management functions, and whether each of these authorities has exercised or is proposing to exercise those functions in response to the flooding event (DEFRA, 2010: 13-14). These reports often provide detailed assessment of local flood risks, and although the Flood and Water Management Act (2010) does not specify that the LLFA must resolve the flooding issue, the conclusions of the reports often identify actions which may reduce the likelihood of similar events or identify measures to mitigate the impacts (see for example CMBC, 2013a).

Stage 4: Options identification

Options identification is a sequential process, which moves from the identification of all potential options, without imposing restraints, to prioritising a subset of those options for subsequent appraisal. Options will include making no intervention (the 'do nothing' approach); continuing with existing interventions (the 'business as usual' approach); adjusting existing interventions to take account of new information; and delaying a decision until more information is available (Willows and Connell, 2003).

Merz *et al.* (2010) provide some basic guidance for options identification. They suggest that the severe uncertainty under which flood risk management decisions are made calls for a very broad spectrum of options, diversification in approach, and the promotion of fail-safe, robust and flexible damage reduction measures. Published advice to practitioners mirrors this call to consider a wide range of options. For example, technical guidance to support the production of Surface Water Management Plans suggests that a range of measures be identified, initially without regard to cost or feasibility, that wherever possible achieve multiple benefits, align with existing investment plans and funding opportunities, engage stakeholders, and take account of local circumstances, opportunities and restraints (DEFRA, 2010: 59-62). The source-pathway-receptor model is revisited here as a means to visualise all of the potential measures that could be identified (Figure 2.2).

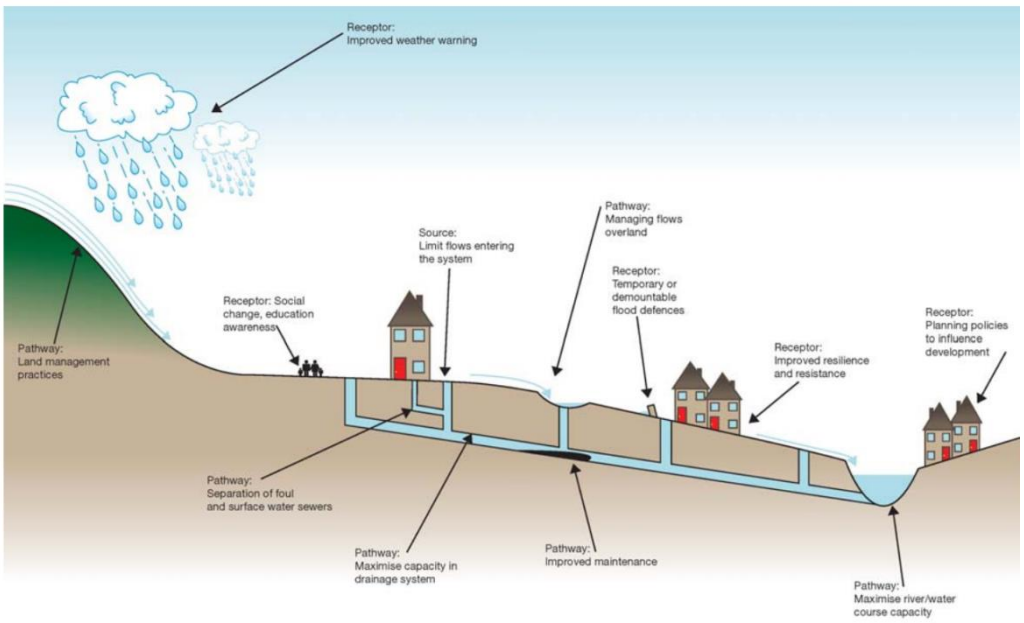


Figure 2.2: Source-pathway-receptor model for options identification (DEFRA, 2010)

Options identification is a creative process that offers an opportunity to engage local stakeholders in decision-making (see Research Questions 1 and 3, p25). Particularly in the early stages, before any appraisal has taken place, drawing on a range of different perspectives and expertises can lead to innovative and novel responses. This engagement can typically involve a mixture of brainstorming, consultation exercises, focus groups and problem mapping (Willows and Connell, 2003). For example, options identification following a major flooding event in Southwell, Nottinghamshire (July 2013) consisted of two workshops held with project partners, specifically URS Consultants, Nottinghamshire County Council (the LLFA) and Southwell Flood Forum (local flood action group consisting of members of the general public) roughly one year after the event. These workshops provided a long list of options that were reduced through screening to a shorter list for subsequent options appraisal (URS, 2015). Despite consultation during early options identification, opportunities for local stakeholder involvement in the screening or options appraisal processes were not provided.

Stage 5: Options appraisal

Options appraisal takes the options identified in Stage 4 and evaluates them against the criteria established in Stage 2. The aim of options appraisal is to provide a robust, evidence-based recommendation of the option that best meets the decision criteria. Decision-making often implies a difficult trade-off between the environmental, economic and social consequences of different options, thus a tiered approach to options appraisal is often encouraged; starting with a broad qualitative assessment, and later employing semi- or fully-quantitative tools if warranted (Willows and Connell, 2003).

An initial broad assessment emphasises the ranking of options in terms of their relative costs and benefits, but does not necessarily involve any quantification. It is particularly useful where the aim is to reduce the long list of all potential options, down to short list meriting more detailed appraisal. General criteria such as technical feasibility, environmental impact, estimated cost and stakeholder acceptability can be used to remove options that are unrealistic. If it is clear that one option performs better than the alternatives, then further appraisal may not be required; however it is more likely that a number of possible options will be taken forwards. It is perhaps in this broad assessment step, where a qualitative approach is often employed, that active participation of local stakeholders could help to support the ranking of options based on local priorities (see Research Questions 1 and 3, p25).

Quantitative methods assess the probable performance of each option in terms of its costs and benefits, in some cases converting this into monetary terms. Cost-benefit analysis is used widely to compare different options and to provide an evidence base for justifying significant investment of public funds (Sayers *et al.* 2002; Messner and Meyer, 2006; DEFRA, 2010). Costs may include capital expenditure, maintenance, operational costs, disruption to services and environmental impact. Benefits include reduced risk to property, business and critical infrastructure, reduced costs of emergency response, reduced risk to life and contribution towards enhancing biodiversity (DEFRA/EA, 2004). Cost-benefit analysis provides a benefit-cost ratio, which describes the return on investment, and can be used as a basis for options appraisal. Stakeholder participation during this stage can support the choice of criteria used for cost-benefit analysis, and to decide which of these criteria can/should be monetised. The intellectual demands of this activity call for capacity-building within local stakeholder groups, to prepare them for a more active role in quantitative options appraisal (see Research Questions 2 and 3, p25).

Stages 6-8: Implementation and monitoring

Following options appraisal, a point is reached where there is the opportunity to decide whether a) the problem was adequately defined in Stage 1; and b) the criteria against which the options were being

assessed were sufficient to determine the preferred option (Willows and Connell, 2003). If deficiencies are found, the decision can be deferred, and the process started anew. Uncertainty about long-term changes, calls for robustness and capacity for adaptation to be built into any preferred solution (Hall and Solomatine, 2008; Merz *et al.* 2010). This may suggest a different option than the preferred option arising from simple cost-benefit analyses.

Representing the uncertainty associated with long-term change is commonly achieved though scenario analysis, which tests the performance of the option across a range of potential futures. Often, it is desirable to conduct sensitivity analysis to provide an indication of which variables/drivers have the greatest influence on the performance of an option. Both scenario and sensitivity analyses employ a variety of methods from qualitative narratives to quantitative modelling of flood events (Hall and Solomatine, 2008; Merz *et al.* 2010). Decisions are frequently made in collaboration, involving groups of experts and local stakeholders, in order to integrate different perspectives (Raadgever and Becker, 2008). These analyses provide information on the key risks and uncertainties, that when effectively communicated to stakeholders, can address misconceptions and misunderstandings, and build support for the preferred option.

Post-implementation, monitoring the effectiveness of intervention options can provide additional information to reduce the uncertainties associated with assessing risk in future decision cycles.

Summary

This section provides a review of the stages in the flood risk management decision-making cycle, and provides an indication of how more active participation might be incorporated at each stage (for a summary see Table 2.3, p43). It primarily addresses Research Question (RQ) 1, as follows:

RQ1: What is flood risk management seeking from participation?

There are several stages in the flood risk management, which can be arranged into a cyclical decision-making process (Figure 2.1, p32). Each of these stages contains different sub-tasks that could potentially benefit from participation (Table 2.3, p44). As a general rule, stages 1-2 and 6-8 require greater *collaboration* of local stakeholders in existing practices, for which they already have the required technical and intellectual competencies. Stages 3-5, which form an embedded process of risk assessment, options identification and options appraisal, are more technical in nature, and are traditionally those from which local stakeholders have been excluded. Recognising the benefits that active participation could bring, it is suggested that participation offers the opportunity for *capacity-building* at these stages, such that local stakeholders can more actively participate alongside technical experts, while they concurrently build the technical skills to take on greater responsibility. This division of stages into opportunities for collaboration and capacity building is summarised in Figure 1.3 (p20).

Table 2.3: Mapping of opportunities, challenges and qualities onto the flood risk management decision-making process

Stage	Tasks potentially benefitting from active participation	Opportunity	Challenges						Key qualities sought (see Paper I, Section 3.1, pI—6)
			1	2	3	4	5	6	
1.Identify problem	✶Understanding reasons behind decision ✶Defining the problem ✶Identifying stakeholders	COLLABORATION	X	X				X	Holistic
2. Establish criteria	✶Developing criteria ✶Dealing with conflict over local priorities			X		X		X	Adaptable
3. Risk assessment	✶Identifying sources, pathways and receptors ✶Understanding spatial variation in vulnerability	CAPACITY-BUILDING		X		X			Accessible
4. Options identification	✶Identifying full range of potential interventions ✶Taking account of local constraints /opportunities		X		X				Accessible
5. Options appraisal	✶Screening of unacceptable options ✶Selecting and ranking appraisal criteria						X	X	Accessible, Adaptable, Evaluative

6. Decision	✶Communicating chosen option to the public ✶Securing public funding to support implementation	COLLABORATION						X	Transparent
7. Implementation	✶Determining level of public involvement in implementation							X	
8. Monitor	✶Determining role of public in maintenance ✶Ongoing education and awareness-raising					X	X		Adaptable

Table 4.1: The role of participation at different stages in the flood risk management decision-making process

Key to challenges
(for descriptions see Table 1.1)

1. Loading is variable
2. Impact is a function of load and response
3. Intervention response is complex and uncertain
4. Spatial interactions are important
5. Temporal interactions are important
6. Rivers are valued in different ways by stakeholders

3. Justifying active participation in flood risk management

Before introducing the participatory modelling approach, or detailing the specific techniques that are used in the two case studies that exemplify it, it is important to recognise developments in the field of participation and highlight what these developments mean for participation in flood risk management. Doing so provides background on the current legislative framework for participation in the UK, the benefits it could realise, and justifies the taking of a participatory approach in flood risk management. It primarily addresses Research Question 1 (p25) by reviewing the reasons behind a change towards more active participation in flood risk management; and goes on to address Research Question 2 (*ibid.*) by identifying, through a discussion of its postulated benefits, what a participatory approach has the potential to deliver.

3.1 Background

Since the 1960s, when environmental issues came to the fore, stakeholder participation in environmental decision-making has been a recurrent theme (Bulkeley and Mol, 2003). In its infancy, environmental decisions were a consensual agreement between state and industry, informed by the certainties of Science. This 'age of authority' positioned scientists as the authoritative voice in their field, informing decisions that only travelled from the top down (Collins and Evans, 2002). Flood risk management drew on the rationality and objectivity of scientific knowledge as the means to identify, explain and manage environmental problems (Jasanoff, 1998), giving rise to the 'technical fix' as a way of working with 'irrational publics' (Brown and Damery, 2002). By the mid-1970s, following the influential work of Michael Polanyi and Thomas Kuhn (Kuhn, 1962; Polanyi, 1966), this way of thinking was coming to an end, replaced by a new 'age of democracy', in which it was seen as necessary and beneficial to draw on extra-scientific actors to inform scientific and technical debates.

The governance of environmental problems evolved over the next two decades, to reach a state where non-participatory forms of governance were seen as 'illegitimate, ineffective and lacking [in] democracy' by both policy-makers and stakeholders alike (Bulkeley and Mol, 2003). Advocates argued early on that deliberative institutions were more likely to respond to the high levels of complexity, uncertainty and collective action problems associated with environmental management (Drysek, 1990). The question remains as to how far to involve stakeholders in flood risk management, and particularly in the more technical activities of flood risk modelling.

Central to these debates has been the question of the level of primacy that should be afforded to scientists and certified experts (i.e. the extent to which flood risk management should be a 'rational' or a 'civic' process) (Owens, 2000). Rational flood risk decision-making implies that public lack the

expertise necessary to make a direct and positive contribution to this process (Wynne, 2006). In a rational process, flood risk decisions are based on evidence derived by scientific means (and directed by scientists), and the identification and appraisal of options is undertaken by those that are qualified to interpret this evidence. This approach is prevalent in flood-risk modelling as a result of the central role played by the complex numerical models employed by specialist consultancies and technical experts. The role of participation is one of providing the public with the knowledge they are perceived as lacking. This approach has significant weaknesses, primarily that it can isolate decision-making from the public, whose interests and priorities it is designed to serve. Where expert information ignores public perception and social understanding of risk, decision-making processes are more likely to make unrealistic assumptions about which management strategies are likely to be successful (RELU, 2010; Lane *et al.* 2011).

By contrast, a 'civic' approach asserts that all decisions that affect the public and the evidence that underpins these decisions should be thought of as public. The emphasis that is afforded to certified, scientific expertise is redistributed amongst certified experts and local stakeholders, together with a new understanding of expertise as being a product of local contexts as well as a property of certain actors (Whatmore and Landström, 2011). Thus civic approaches introduce the idea that 'uncertified local experts' with situated knowledge of flooding in their localities are an important source of knowledge that can engage with experts in the co-production of better evidence bases and help to better interpret those that are produced. However, the practical incorporation of civic approaches into the formulation, evaluation and application of flood risk models requires tools that can structure, formalise and combine the uncertified knowledge of local stakeholders with the certified knowledge of experts, and support the co-production of knowledge (i.e. expert knowledge is enhanced by the input of local stakeholders and *vice versa*). These must be sufficiently flexible to formalise a wide range of knowledge, yet sufficiently credible to ensure that outputs have legitimacy and practical value for experts and non-experts alike.

3.2 Three reasons for change

Three key reasons underpin the move towards a civic approach to participation in flood risk management: the need to meet legislative demands; the need for flood risk solutions that have greater public acceptance; and the need for improved evidence bases to support decision-making. The first of these is procedural in focus, and broadly identifies what flood risk management is seeking from participation (see Research Question 1, p25). The other two have more epistemic aims which map closely to recognised benefits of participation in water management studies (*cf.* Voinov and Gaddis, 2008; Von Korff *et al.* 2012). The first primarily assesses what participation can deliver (see Research

Question 2, p25), while the second revisits Research Question 1 (*ibid.*), by asking more specifically what the practice of flood risk *modelling* seeks from participation. These aims are centred on the delivery of flood risk management decisions of greater quality and acceptability through the enhancement of flood risk knowledge (in all actors), and the application of this knowledge to complement existing flood risk models, and promote consensus around the decisions that model outputs ultimately direct.

These discussions are continued in Paper I (pI—3-I—8), Paper II (pII—4) and Paper III (pIII—3-III—6). As a result of their different locations in the flood risk management process (Figure 1.3, p20), Paper II (Hebden Bridge case study) focusses these discussions on decision-making, while Paper III (Southwell case study) focuses on the perception and governance of risk. Finally, Paper IV (pIV—5-IV—8) looks at how to evaluate participatory processes by exploring the different aspects of effectiveness.

Reason 1: Meeting legislative demands

Flood risk models are a primary evidence base for local flood risk management, which operates within a broad legislative context that exists at regional, national and international levels. The last two decades has seen the emergence of several high-level resolutions and treaties that inform water legislation across the world. A common component of these has been the stipulation of greater participation in decision processes affecting water management issues that extends beyond consultation to include active participation at all stages of decision-making processes.

At the international scale, Principle 10 of the Rio Declaration (UNEP, 1992) and the United Nations Agenda 21 (UNCED, 1992) have both stipulated requirements for participation; albeit as an overarching principle of all environmental management rather than a specific requirement for flood risk modelling and management. Similarly, the right of the public to participate in environmental decision-making processes is also enshrined as a pillar of the Aarhus Convention (UNECE, 1998), which has now been ratified by 45 countries. The United Nations Dublin Statement on Water and Sustainable Development is arguably of more specific relevance to flood-risk science because it asserts that water management should be founded on participation, and that this should inform 'decisions at the lowest appropriate level, in order to bring decision-making as close as possible to those affected' (ICWE, 1992: 19). This implies that, at the local scale at which flood risk management is usually enacted, and given the high degree of impact that results from flood modelling can have on local communities, high levels of participation in the modelling processes should be operating at local scales. Indeed, if flood-risk decision-making is to be 'brought as close as possible to those affected', there is an implicit need to ensure that participants are able to engage with and understand the model-based evidence that informs the decision-making process.

International-level policy is inevitably reflected in regional, national and local legislation that governs water and flood management. In the European Union, the European Public Participation Directive (EC, 2003) requires participatory governance to be a core and systematic element of all environmental policy and practice – including water management. Similarly, the European Water Framework Directive (EC, 2000) and European Floods Directive (EC, 2007), which direct flood management policy in European Community member states, require the encouragement of 'active involvement of all interested parties' in its implementation (EC, 2000: Article 14.1), and the delivery of water management that is supported by collaboration and inter-disciplinary learning (Mostert, 2003; Nastar, 2009). Therefore, in local flood management contexts, where models are a primary source of information to the decision-makers that are responsible for implementing the legislation, flood-risk modelling processes are expected to include and benefit from active participation so that alignment between evidence bases, the decision-making processes and legislative requirements are demonstrated. This implies that flood risk management seeks a high degree of transparency and accessibility in active participation (Research Question 1, p25)

Reason 2: Realising the benefits of participation

Several clear benefits of adopting the civic approach have been argued (Von Korff *et al.*, 2012), which are equally applicable to flood risk management. These include improved legitimacy, lower costs and increased civic competency and social capital (Fiorino, 1990; Laird, 1993; Renn *et al.*, 1995; Webler *et al.*, 1995; Webler and Tuler, 2001; Beierle and Cayford, 2002; Reed, 2008; Klinke, 2009; Von Korff *et al.*, 2010). Normative benefits include a reduction in the marginalization of citizens (Gaventa, 2002), an increase in trust (Yearley, 2005), and an enhanced level of accountability (Jasanoff, 2003; Evans and Plows, 2007). Pragmatic benefits include better adaptation to local cultural, social and environmental contexts (Reed, 2008), improved information inputs (Callon, 1999; Reed *et al.*, 2009), the fostering of public ownership (*cf.* Johnston and Soulsby, 2006) and a reduction in conflicts (Irwin, 2009).

However, it is also worth noting that participation does not automatically lead to legitimacy (Korfmacher, 2001), and that the efficiency of any participatory process depends upon the social relations between stakeholders (expert and non-expert), and their ability to communicate and exchange knowledge. In this respect, the choice of appropriate tools is critical (see Research Question 3, p25) (Mendoza and Prabhu, 2006). If poorly implemented, participation can have negative effects that include stakeholder disillusionment, unbalanced decisions, and increased time to reach decisions (e.g. Brett, 1996; Coglianese, 1997; Eversole, 2003; Höppner *et al.,* 2003; Carpini *et al.,* 2004; Irvin and Stansbury, 2004; Barreteau *et al.,* 2010).

Reason 3: Incorporating consequence into flood risk models

The shift from flood *hazard* management to flood *risk* management has seen a significant change in the way that flooding is understood and managed in many countries that has promoted the need for tools that can support wider participation in flood modelling exercises. The traditional requirement for quantifying and reducing flood likelihood through physical observations, hydrologic and hydraulic models has been augmented by a requirement to understand and quantify flood consequence (Figure 3.1). This requirement introduces additional scope to flood risk management that has both physical contexts (e.g. where inundation occurs and how severe it is) and social contexts (e.g. whether social actions can promote resilience or adaptation (*cf.* Cutter *et al.* 2008)). It encompasses human decisions and actions that are taken before, during and after a flood event, and that combine with hydrologic and hydraulic processes to determine the overall impact that a given flood event will have.

The consequences of flooding are quantified in terms of vulnerability, which is usually expressed as the exposure of people and assets to floods, and by the susceptibility of these elements at risk to suffer damage (Apel *et al.* 2008). Therefore, the ability to represent and model the specific social strategies, actions and causalities that occur within communities is central to understanding flood consequence at any given location. This representation can only be achieved with a high degree of local participation in the risk modelling process itself.

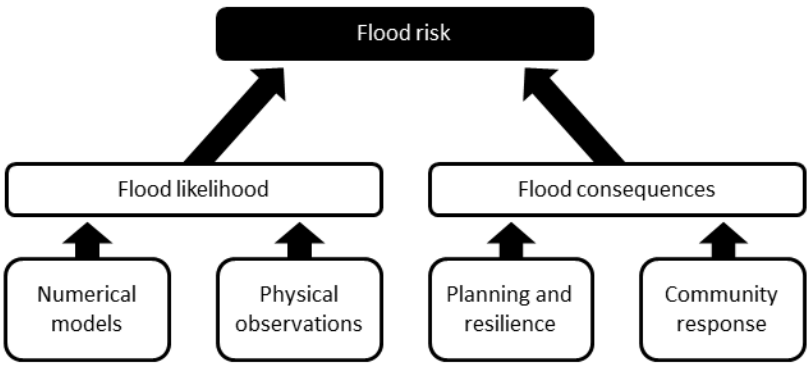


Figure 3.1: The components of flood risk

The close coupling of flood hazard and consequence, and the complex interactions that occur between the hydrologic systems and communities means that local flood risk models must be capable of representing and adapting to the complexity of both hydrological and social systems and the interdependencies that exist between them. Importantly, the physical and social systems that determine flood risk are not certain (e.g. Beven and Binley, 1992; Freer *et al.* 1996). In physical systems,

uncertainties exist in the data that drives models, as well as the model structures and parameters themselves (Wheater, 2002). In social systems, variability in human behaviour and values, coupled with societal and technological randomness cause uncertainty in models of social systems (Van Asselt, 2000).

Physical and social systems are also not static - meaning that the degree of system complexity to be modelled may be dynamic. Future climate change, and its impact on hydrological systems, means that historical, event-based approaches to flood modelling are being replaced by analyses that consider a much wider range of hydrological processes and flood scenarios; taking into account how these might manifest themselves both spatially and temporally (Brown and Damery, 2002; Hall *et al.* 2003). Similarly, social systems are known to be highly adaptive to changing environmental conditions (e.g. Adger, 2003). As systems change, so the number of variables and nature of interdependencies and uncertainty changes (Orr *et al.* 2007). Thus, modelling techniques are needed that can handle uncertainty and that are easily adaptable so that they can be easily and rapidly updated as more knowledge is acquired and as systems change. In this way the match between portfolios of measures and the functioning and needs of particular localities at particular times can be better ensured (Hall and Solomatine, 2008).

4. Studying participation

Having outlined the process of local flood risk decision-making, and explored the reasons for a change in the role of participation in that process, this section looks at how participation is studied in this thesis. It explores three facets of participatory study which require careful consideration: process design, stakeholder analysis and evaluation.

4.1 Approaching process design

It is widely recognised that despite the growing body of research on participation, and the use of participatory processes in a range of environmental fields, the question of how to design these processes receives little attention (von Korff *et al.* 2010). In a reaction to this lack of technical guidance in the literature, a wealth of practitioner guides have been developed to support process design. These guides have two main limitations: first that the experiential knowledge upon which they are often based could be considered suspect because it has not been the subject of peer review, and second that the guides often focus on a very narrow field (Webler, 1999).

In a discussion on participatory process design, it is important to note two points. First, that the benefits of participation (outlined in Section 3) cannot be assumed, and that processes that are poorly designed can bring about negative effects, including stakeholder disillusionment, poor decisions, increased conflict and loss of time and resources (*cf.* Höppner *et al.* 2003; Barreteau *et al.* 2010), it is important to reflect on how process design was approached in this thesis, in order to maximise the potential for the benefits of participation to be realised. Second, that although participation is often used to produce a product, the process of *doing participation*, inclusive of all of the participatory activities conducted with stakeholders, is considered here as having intrinsic value. Often, evaluation has shown that participants value the process more than the tangible outcomes it produces (Voinov and Bousquet, 2010).

Approaching process design starts with a consideration of the initial design context, which extends to include *inter alia* the stakeholders involved, their goals and expectations of the process, and the existing levels of conflict between them. These factors influence the participatory activities that are then chosen to form the participatory process.

In the design of the Hebden Bridge and Southwell processes, preliminary interviews with stakeholders enabled the contexts to be better understood. In Hebden Bridge, semi-structured interviews were used to give participants the freedom to explore their goals, the process aims, and objectives for improved management of flooding in the catchment (see Appendix 1). The process aims were presented to the

participants to ensure participant expectations were clear at the outset. More flexibility was afforded to the catchment objectives, which were updated after each interview, and provided a direct input into the first stakeholder workshop. In Southwell, the preliminary interviews served three main objectives, first to define the problem, second to explore (and thereby manage) expectations of the process, and finally to establish a baseline of social capacity within the community, that could then be reassessed after the process (see Appendix 4). The first two objectives were addressed using open questions that facilitated discussion, while the final objective was met using a set of statements which the respondent rated on a Likert scale.

An outline workshop schedule was provided to participants at the start of the process, although it was acknowledged that changes would inevitably occur as the workshops progressed. In Hebden Bridge, the participatory activities were largely based around a design guide produced to support the use of Bayesian networks in natural resource management (Cain, 2001), which was easily modified to meet the needs of flood risk management. In Southwell, participatory activities were concatenated from the approaches used in a series of applications reported in the peer reviewed literature (*cf.* Stave, 2002; 2003; Tidwell *et al.* 2004; Winz *et al.* 2009).

4.2 Approaching stakeholder identification and analysis

This thesis adopts a normative approach to stakeholder analysis, which identifies and prioritises stakeholders that are morally responsible as a result of their influence on, and/or interest in, local flood risk management. This approach differs from instrumental stakeholder analysis, which is largely concerned with identifying stakeholders whose behaviour might be managed to achieve desired outcomes (Reed *et al.* 2009).

The pre-existing stakeholder networks in Hebden Bridge and Southwell provided a sound starting point for stakeholder identification, and were significant both in the selection of these communities and the methods chosen for subsequent stakeholder analysis. In Hebden Bridge, these networks consisted of stakeholders from different organisations (including the Environment agency, several environmental charities, local universities and water utility companies), who were already meeting on a quarterly basis to discuss environmental management in the catchment, with a focus on the uplands. In Southwell, a successful local action group, Southwell Flood Forum, chaired multi-agency meetings of local stakeholders. The membership of the Forum included a high proportion of local residents, which was reflected in the case study participants.

These networks facilitated, in both cases, the use of an iterative, top-down stakeholder identification methodology, commonly known as ‘snowball’ or ‘referral’ sampling (Harrison and Qureshi, 2000; Hair

et al. 2010). In this methodology, semi-structured interviews with existing stakeholder contacts (see Section 4.1) provide new stakeholder contacts in an iterative manner.

In Hebden Bridge, stakeholders were organised according to a simple influence-interest matrix, which led to their classification as context setters, key players, subjects and the crowd (after Eden and Ackermann, 1998; De Lopez, 2001) (Paper II, Section 4). In Southwell, the stakeholder typology was improved in an attempt to align it more closely with the attributes that drive participation in flood risk decision-making, namely responsibility, expertise and affection (Paper IV, Section 4). In this new stakeholder typology, developed after Freeman (1994) and Mitchell *et al.* (1997), stakeholders sharing two or more of these attributes are prioritised for participation. Stakeholders possessing all three attributes are termed 'definitive stakeholders', and while they are likely to be few in number, they often provide the glue that holds the group together by having the greatest understanding of the different priorities in the community, and appreciate the range of solutions that is needed to meet these needs.

Both of these techniques allow the stakeholder typology to be tailored to the requirements of flood risk management, and allow the process manager to prioritise stakeholders based on carefully considered attributes. The use of the Venn diagram typology in the Southwell study ensures that where stakeholders possess two or more attributes, rather than creating uncertainty over how they should be classified, this is seen as advantageous and those stakeholders are prioritised for participation. A potential weakness of the technique is that some stakeholders, such as those that have indirect expertise (e.g. policy knowledge, project management skills) could fail to be identified.

4.3 Approaching evaluation

The approach to evaluation in this thesis aims to broaden previously process-centric evaluation frameworks, to assess both the social and the substantive outcomes of participation, that include *inter alia,* the building of trust, the development of relationships both within and outside the local flood risk management community, and the promotion of social learning (McDaniels *et al.* 1999; Buchecker *et al.* 2013). Central to the approach taken to evaluation in this thesis is the assessment of social capacity, and how this as changes as a result of participation. The methodological difficulties in evaluating the social effects of participatory processes are well documented, and suffer from uncertainties in terms of the temporal stability of results, influencing factors/context, and small sample sizes (Buchecker *et al.* 2013). In response, this thesis evaluates three forms of social capacity (knowledge, motivational and network capacity), which together provide an indication of future social change (*ibid.*).

Having stressed the importance of including both social and substantive outcomes within evaluation, it remains critical to monitor the quality of the process (Section 6.1) in order to recruit and then retain a motivated group of participants (Hartig *et al.* 2010).

For both process and social outcomes evaluation, a simple set of attributes were sought from previous studies/frameworks, that suited the evaluation of flood risk management, a field in which governance and decision-making are increasingly being devolved to the local level and greater emphasis is being placed on community resilience (Steinführer *et al.* 2009). Five attributes (accessibility, deliberation, representation, responsiveness and quality) were developed from the principles of effective participation (Fiorino, 1990) and clarified through the use of success statements to which participants could easily relate. In both the Hebden Bridge and Southwell case studies, these success statements were presented to participants in a series of post-project interviews. Participants were asked how far they agreed (on a Likert Scale from 1-5) with each statement, and also to provide further evidence on why they thought the statement was achieved or not.

In vivo coding was used to draw out key points that illustrated how far each statement was met. This coding method was also used to convert interview transcripts into substantive outcomes, identifying specific short term goals that were bespoke to the case study.

5. Participatory methodologies and rationale

Meeting the challenge of radical change in flood risk management will require the application of new approaches and techniques that can support efforts for greater co-production of models and model-based evidence, via the formal representation and structuring of knowledge from all stakeholders (i.e. both technical and situated knowledge). At present, research into such tools within the specific context of flood-risk management remains limited, and there are relatively few studies or guidance to direct Lead Local Flood Authorities and other local organisations. However, there is a breadth of relevant literature that is focussed on methods for delivering stakeholder participation in the wider context of environmental decision-making and management, which represents an important resource. The methods applied in these studies are geared towards planning and conducting an analytical process (e.g. the development and application of a model) with those whose environment and community is under study (Bergold and Thomas, 2012). This means that the analytical process is guided by, and develops out of, the convergence of two perspectives—that of technical expertise and local, situated knowledge – an approach that has become known as participatory modelling (Voinov and Gaddis, 2008).

Participatory modelling is a broad field that encompasses both mechanistic approaches and practical tools that are used to deliver participation in a modelling process (Voinov and Bousquet, 2010). Whilst

the two are often conflated, there is an important contrast between them. On the one hand, participatory modelling *approaches* are the mechanisms through which participation is enacted. They include the development, organisation and execution of the activities through which participants are engaged and system knowledge is elicited and shared. A range of approaches have been developed and used in catchment management contexts (e.g. shared vision planning (Werick and Whipple, 1994); group model building (Vennix, 1996; Pahl-Wostl and Hare, 2004); mediated modelling (Van den Belt, 2004) and companion modelling (Barreteau, 2003)) to support participants in achieving effective engagement with, and epistemic outcomes from models.

On the other hand, participatory modelling *techniques* provide the mathematical framework by which interdisciplinary data, including participant knowledge, can be captured and analysed (Batchelor and Cain, 1999). They act as an interface between stakeholders and modellers, to formalise and structure knowledge; enabling its heuristic exploration in ways that can direct the co-production, evaluation and application of flood-risk models, and enhance the understanding of all actors in the modelling process. It is these techniques, and the opportunities they offer for formal representation and structuring of participant knowledge to direct and interrogate the co-production, application and evaluation of flood risk models, which are explored throughout this thesis (see Research Question 3, p25).

Participatory modelling techniques aim to be accessible and understandable to all participants, regardless of their technical expertise, and can be used to structure participants' system and causality knowledge so that the implications of changes under different conditions can be explored through 'what if…?' style questions (Sterman, 2000; Mance *et al.* 2002; Stave, 2003; Özesmi and Özesmi, 2004). In the case of flood risk, it is the combined understanding of cause and effect in hydrologic, hydraulic, social and infrastructure systems that must be represented. Thus, techniques offering potential are those that have emerged from causality and systems modelling (e.g. systems dynamics models (Forrester, 1961), causal loop diagrams (Sterman, 2001), fuzzy cognitive mapping (Harary, 1965; Axelrod, 1976; Ackermann *et al.*, 1991) and Bayesian networks (Pearl, 1985; 1988)).

The benefits of participatory modelling are distilled to five key qualities (Table 4.1), which are used to review three popular techniques in Paper I, namely Bayesian networks (Section 5.1, pI—14), system dynamics (Section 5.2, pI—19) and fuzzy cognitive mapping (Section 5.3, pI—23). These qualities are later mapped onto the stages in the flood risk decision making process (Table 2.3, p44).

Table 5.1: Key qualities of participatory modelling

Key quality	Potential benefits for flood risk modelling
Accessible	The ability to enable a wide range of stakeholders to become involved in the development, evaluation and refinement of flood risk models. Interfaces are simplified – possibly graphical - and knowledge is represented conceptually. Methods used to structure knowledge have low complexity.
Transparent	The ability to quantify and communicate the impacts, limitations and uncertainties associated with different potential decisions and actions. Knowledge representation is sufficiently clear that it can be traced, along with the reasons behind different outcomes.
Adaptable	The ability to encapsulate the specific realities and dynamics of local flood contexts that are readily updated as more knowledge is acquired and/or as social and hydrologic systems change. Methods by which knowledge is structured support easy adjustment and extensibility.
Evaluative	The ability to facilitate the exploration of scenarios and movement of stakeholders and decision-makers towards consensus in identifying preferred options. Re-instantiation and / or recalibration of knowledge representation is straightforward.
Holistic	The ability to incorporate and integrate a broad knowledge base – including physically and socially-derived information. Holistic tools will also be developed to support the structuring, representation and integration of knowledge as both quantitative and qualitative information.

In flood risk management, the relatively few studies employing these techniques results in a review which is based almost entirely in theoretical literature. In order to test the participatory approach (Paper I) and the evaluation framework (Paper IV), two UK case studies were undertaken to evaluate the potential of two popular techniques, namely Bayesian networks (Paper II) and system dynamics (Paper III), in terms of their capacity to support local flood risk management at a specific point in the flood risk management decision-making process. These case studies address Research Question 3, by providing evidence for the potential benefits of each technique at specific stages in the decision-making process (Figure 1.3, p20), in addition to providing an exemplification of the evaluation framework presented in Paper IV (Research Question 4, p25).

Sections 5.1 and 5.2 detail the techniques employed in each of the two case studies. They provide a theoretical background to each of the techniques going beyond that which each individual paper has

scope to include, while the papers themselves detail how the technique was applied in the specific participatory context of that case.

In the first case study, participants co-produced a Bayesian network model to identify potential flood risk interventions and prioritise a subset of these for subsequent traditional options appraisal in Hebden Bridge, West Yorkshire. This study forms the basis of Paper II. In the second case study, participants used elements of system dynamics to explore perceptions of risk during a recent flood event in Southwell, Nottinghamshire (July 2013). They went on to assess how different small-scale interventions (i.e. those that can be implemented by the individual or community) could reduce the vulnerability and exposure of receptors at different flood water depths. This study forms the basis of Paper III.

5.1 Bayesian networks

Bayesian networks are a graphical causal model consisting of a directed acyclic graph, with relationships between variables defined using conditional probability. They utilise probability distributions that encode our belief about some parameter based on the current state of information on other nodes in the network. Instead of accepting or rejecting a hypothesis, they ascribe a higher or lower level of certainty to outcomes (Mount and Stott, 2008). The technique was first developed by Pearl (1985; 1998) and later generalised by Varis (1995).

The technique utilises conditional probability, which implies that the probability of an event changes when we have evidence of other events. Visualise two events A and B, which share intersection AB (Figure 5.1). If we know that event B has occurred, then to evaluate the probability that A has occurred we take the proportion of AB to B.

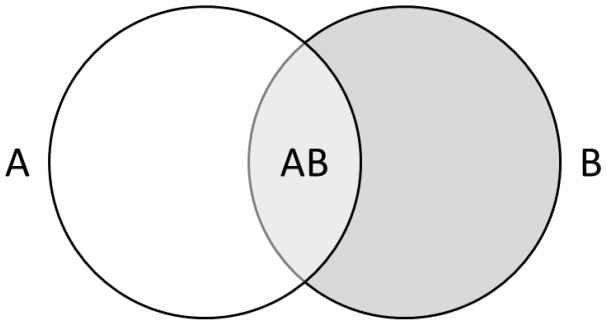


Figure 5.1: P (A|B) as the proportion of AB to B

This provides the conditional probability for A given B (Equation 5.1).

$$P(A|B) = \frac{P(A,B)}{P(B)} \; where \; P(B) > 0$$

Equation 5.1: Conditional probability

The expression of conditional probability can be rewritten to obtain the simple form of Bayes' theorem (Equation 5.2).

$$P(A|B) = \frac{P(B|A) * P(A)}{P(B)}$$

Equation 5.2: Bayes' theorem

A Bayesian network consists of a series of nodes, each with a finite set of mutually exclusive states, linked by causal relationships. In the convergent graph structure shown in Figure 5.2, we see that nodes

A and B are conditionally independent, and node C is conditionally dependent on A and B. In Bayesian networks parlance, we say that A and B are the *parents* of *child* C.

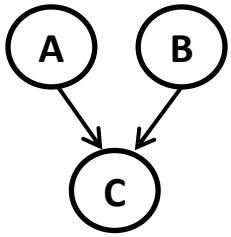


Figure 5.2: Convergent graph structure

Causal relationships, such as that between A and C, are not certain nor absolute. The occurrence of A does not necessarily lead to C being in a specific state, but instead influences the probability that C is in each of its states.

To transform this into a Bayesian network we require the prior probabilities of parentless nodes, $P(A)$ and $P(B)$, as well as the conditional probability $P(C|A,B)$, which reads 'probability of C given A and B'. To simplify the estimation of these, variables A, B and C are given discrete states allowing characterisation of the continuous probability distributions through a discretised conditional probability table.

Once the conditional probability table has been populated, propagation of information through the network allows the user to model how decisions and observed conditions (collectively termed 'evidence') affect the probable conditions at other nodes.

For this example, let both A and B have two states, *a1, a2, b1 and b2.* Downwards propagation of evidence through the Bayesian network is based on the Law of Total Probability (Equation 5.3).

$$P(c1) = P(c1|a1,b1).P(a1,b1) + P(c1|a1,b2).P(a1,b2) + P(c1|a2,b1).P(a2,b1) + P(c1|a2,b2).P(a2,b2)$$

Equation 5.3: Law of Total Probability as applied to the network in Figure 5.2

Upwards propagation of evidence through the Bayesian network is based on Bayes' Theorem (Equation 5.4).

$$P(a1,b1|c1) = \frac{P(c1|a1,b1).P(a1,b1)}{P(c1)}$$

Equation 5.4: Bayes' Theorem as applied to the network in Figure 5.2

New knowledge can be propagated by modifying the conditional probability table, or by instantiating variables into particular states (i.e. setting the probability of a particular state to 1). This process of instantiation removes the uncertainty from a node, and can be used to simulate decisions or other action that has or will possibly be made (Varis and Kuikka, 1997).

5.1.1 Strengths of Bayesian networks

Bayesian network modelling offers the following strengths that support its use as a participatory technique in the management of flood risk:

1. The encouragement of whole system thinking and understanding
2. The scope for bottom up (diagnostic) and top down (exploratory) reasoning
3. The ability to work with the best available (often scarce or missing) data
4. The ability to combine knowledge from a range of different sources
5. The explicit treatment and communication of uncertainty and risk

First, they encourage participants to think about how different system elements are interlinked, and how several interventions, working in combination, are often needed to achieve their objectives.

Exploring the effects of different interventions is facilitated by both bottom-up (inferring the cause/s given evidence of the effect) and top-down reasoning (inferring the effect given evidence of the cause/s) (Castelletti and Soncini-Sessa, 2006). The first is useful for diagnostic tasks while the second is commonly used for descriptive and explanatory tasks. As the values in the each conditional probability table (CPT) are independent of the values in other CPTs, they can be locally updated (*ibid.*). This property allows a model to be adapted and improved as new data and knowledge becomes available.

In flood risk management, relationships can be difficult to quantify, and data may be difficult to obtain or not readily available to support the completion of CPTs. A benefit of Bayesian networks is that the approach allows the use of both observed data and subjective probabilities to determine prior and conditional probabilities (Nakatsu, 2009). This makes them particularly useful when there is scarcity and uncertainty in the data required to make a decision (Henriksen and Barlebo, 2008).

Since nodes in Bayesian network are modelled using probability distributions, risk and uncertainty can be estimated more accurately than in models that only use mean values (Aguilera *et al.* 2011). The causal link between input and output nodes propagates uncertainty to these output nodes, which is subsequently communicated using probability distributions (Landuyt *et al.* 2013).

5.1.2 Limitations of Bayesian networks

The structure of Bayesian networks also results in some notable limitations:

1. Discretisation of continuous variables

   Most data available for models are continuous or hybrid, and although Bayesian networks can manage these, the limitations are restrictive. Commonly, variables are discretised into a few states, which may lose some of the finer relationships between variables (Aguilera *et al.* 2011). Automatic discretisation techniques have been developed, although no method is entirely satisfactory and expert opinion is often sought (*cf*. Uusitalo, 2007).

2. Absence of feedback loops

   Bayesian networks are acyclic and thus do not support feedback loops that offer usefulness in modelling dynamic systems (Uusitalo, 2007).

3. Dealing with time

   Temporal dynamics can be modelled in Bayesian networks by having a series of coupled networks each representing a time slice. However, the computational burden required to solve probabilistic relations increases exponentially with the number of time slices, leading dynamic systems to quickly become intractable (Zorrilla *et al.* 2010; Aguilera *et al.* 2011).

5.1.3 Using Bayesian networks in a participatory setting

The strengths and limitations of using Bayesian networks in a participatory setting are further explored in Section 5.1 of Paper I (pI—14) and Section 5.2 of Paper II (pII—15). In summary, they provide a mathematical framework for integrating data from a number of sources, facilitating the modelling of complex systems (Batchelor and Cain, 1999). Involving stakeholders in the construction of Bayesian networks has been shown to improve their validity (Henriksen *et al.* 2007), in addition to the benefits that arise from involvement throughout the modelling process, which encourages stakeholders to identify all of the information/data required to formally express the system, elucidates gaps in their knowledge, maintains transparency in the modelling process, and helps them to better understand, and take ownership of, the decisions that models ultimately direct.

When used as an instructive tool, Bayesian networks can be used to identify where further modelling and research will lead to the greatest improvements in model confidence (Smith *et al.* 2007). Often this takes the form of sensitivity testing, through which stakeholders observe the effects of implementing a specific intervention (top-down exploration), or assess which interventions are most sensitive to the achievement of a specific objective (bottom-up exploration). Combined with the technical strengths outlined above and in Paper II (Section 5.2, pII—15), accessibility is afforded through widely available and low-cost software packages. These technical capabilities suggest that Bayesian networks offer particular potential to support the risk assessment, options identification and options appraisal stages of the decision-making process (Figure 1.3, p20).

However, co-producing Bayesian networks with stakeholders poses a number of challenges (Landuyt *et al.* 2013). Firstly, a model can be perceived as subjective and unscientific if there has been an over-reliance on the use of expert knowledge in the definition of conditional probability tables. To challenge this threat, it is recommended that the outcomes of Bayesian network models are used to complement traditional numerical modelling practices. Second, model credibility can be low due to the necessary simplification of social and physical systems. These simplifications, a number of which are expanded on in Paper II (Section 5.3, pII—17), include the limitation of nodes to two discrete states (to reduce model complexity) and the extrapolation of conditional probability table values from a subset elicited from stakeholders (to reduce time and resource demands on volunteer participants). They are critical given the range of technical expertise and experience in those participating.

5.1.4 Case study summary: Hebden Bridge

Paper II reports on a Bayesian network model that was developed in Hebden Bridge to identify potential flood risk interventions and prioritise a subset of these for options appraisal. The methodology followed the general approach outlined in Marcot *et al.* (2006) and Cain (2001), and consisted of six evening workshops, flanked by pre- and post-project interviews.

Hebden Bridge, West Yorkshire experienced two major instances of flooding within the space of three weeks in the summer of 2012 (22 June and 9 July) which affected 219 and 100 properties respectively (CMBC 2013a; 2013b). Following these events, and a lack of consensus over how to effectively manage flood risk in the town, a collaborative project was established between the Environment Agency, Calderdale Metropolitan Borough Council (the Lead Local Flood Authority) and researchers from the University of Nottingham. The project aimed to assess the potential for a Bayesian network model to be employed with a participatory modelling approach, to identify flood risk management options that structured situated knowledge alongside that of technical experts.

When situated within the decision-making process, the Hebden Bridge case study supported Stages 3 and 4, namely risk assessment and options identification (Figure 1.3, p20). While it also provided some investigation of the problem and established objectives by which its outcomes could be evaluated (Stages 1 and 2), this was not the focus of the study. Neither did it extend to using the objectives developed in the project for detailed options appraisal (Stage 5). Paraphrasing the aims detailed in the paper (Paper II, Section 3, pII—5), investigating local flood risk management objectives allowed for an examination of the potential effect of alternative management options, and exploration of those options such that a subset could be shortlisted as warranting further appraisal.

The focus on Steps 3 and 4 locate this case study within the embedded cycle of options identification and appraisal (see Figure 5.3), suggesting that the primary aim of the study was to explore the potential for the participatory modelling technique employed to provide opportunities for *capacity-building* within the community (see Figure 1.2, p19).

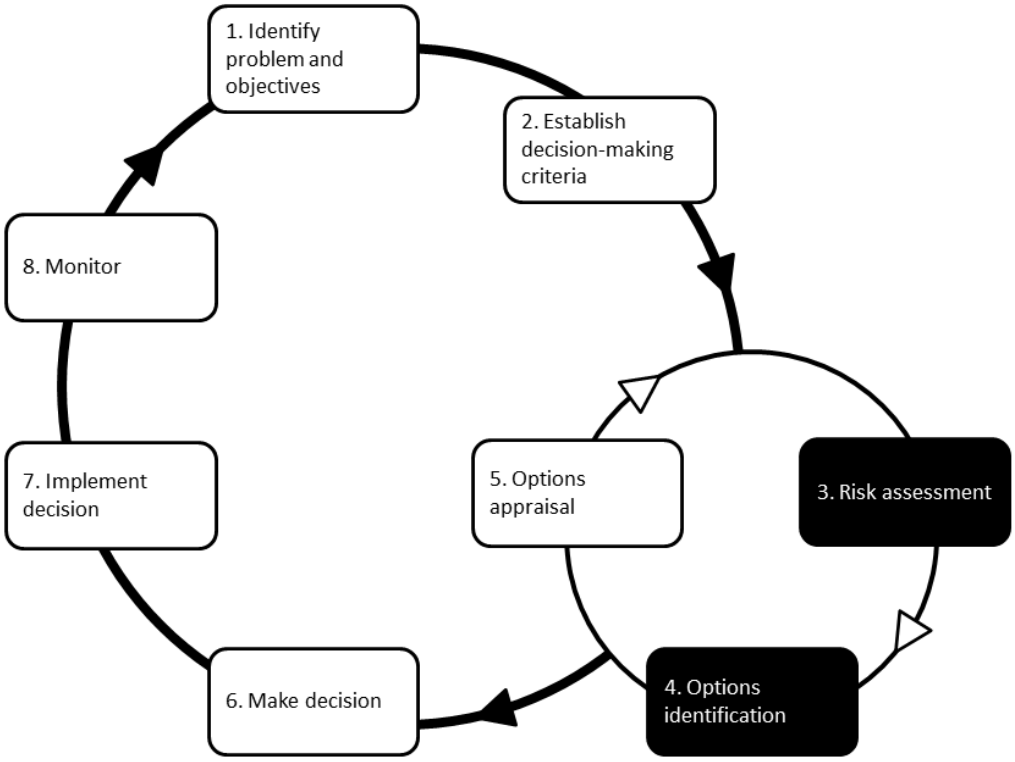


Figure 5.3: Stages of the decision-making process supported by participatory modelling in the Hebden Bridge case study (highlighted in black)

5.2 System dynamics

System dynamics is a feedback-based object-oriented simulation technique, based on the premise that system structure gives rise to observable and predictable system behaviour (Forester, 1961). Models built using system dynamics have been applied to, *inter alia,* river basin planning (Palmer 1994; Palmer *et al.* 1999; Tidwell *et al.* 2004), water resources/security (Simonovic *et al.* 1997; Simonovic and Fahmy, 1999; Stave, 2003; Khan *et al.* 2005), reservoir management (Ahmad and Simonovic, 2000), and salinization (Saysel and Barlas, 2001).

System dynamics employs both qualitative modelling (e.g. causal loop diagrams or hexagons) to improve participants' conceptual understanding, and quantitative modelling (e.g. stock and flow diagrams) to explore the effects of different interventions strategies (Winz *et al.* 2009). Initially, participants often co-produce causal loop diagrams of a system to depict the feedbacks and relationships that form the system structure, such that a dynamic hypothesis can be developed (Randers, 1973; 1980; Homer and Oliva, 2001). Causal loop diagrams can be used standalone for learning purposes (e.g. exploring feedback mechanisms with users), but are rarely employed for drawing conclusions about their dynamic implications (Paich, 1985; Homer and Oliva, 2001). In the example shown in Figure 5.4, variables A, B, C and *r* are arranged into two feedback loops. Relationships between variables are shown by arrows with both direction and polarity.

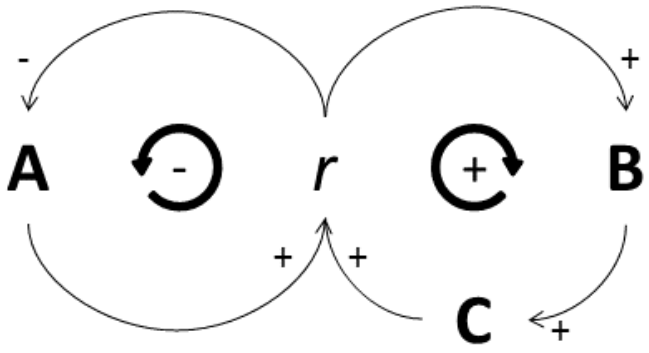


Figure 5.4: Causal loop diagram

Causal loop diagrams lack reliability for behaviour inference/prediction (Richardson, 1998), and as a result simulation modelling is often used to convert the diagram into an explanatory model through which the dynamic hypothesis can be formally explored. This second step usually involves conversion of the causal loop diagram into a stock and flow diagram (Figure 5.5). In this example, two stocks (A and B) are linked by a flow (*r*). The levels of A and B (i.e. how full each stock is) describe the condition

of the system at a particular time, with the rate of flow (*r*) controlling how quickly those levels are changing.

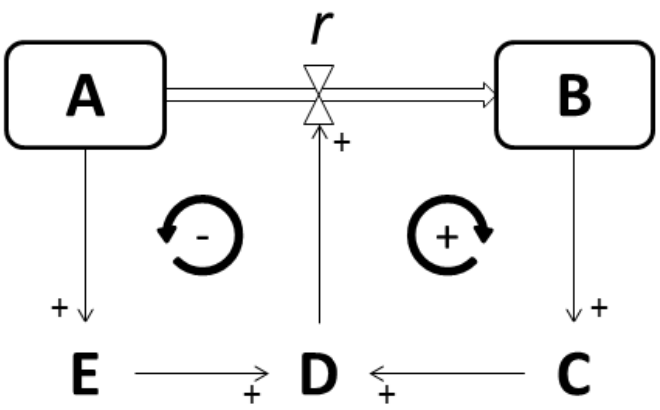


Figure 5.5: Stock and flow diagram developed from Figure 5.4

Three additional variables (C, D and E) act to influence the stocks and flows. Relationships between variables are shown by directional arrows with either negative or positive polarity. Where these complete a cycle, a feedback loop is generated. Figure 5.5 contains both a positive (self-reinforcing) feedback loop (Equation 5.5) and a negative (self-correcting) feedback loop (Equation 5.6).

$$\overrightarrow{BCDrB}$$

Equation 5.5: Positive feedback loop

$$\overrightarrow{AEDrA}$$

Equation 5.6: Negative feedback loop

Where multiple feedback loops interact, as in Figure 5.5 and most complex real world systems, it is generally impossible to determine the system dynamics without turning to computer simulation (Sterman, 2001). Before a simulation is run, model parameters and initial conditions are entered. These can be estimated from statistical means, market research data, expert opinion and any other source of quantitative or qualitative data (*ibid.*). During simulation the model takes a number of time steps, with system variables updated after each step (Guo *et al.* 2001).

5.2.1 Strengths of system dynamics

System dynamics offers the following strengths that support its use as a participatory technique in the management of flood risk:

1. An established and flexible methodology
2. A focus on system structure
3. The ability to model temporal dynamics

The technique allows participants to see how changes in basic system elements can affect the system dynamics of the future, and is therefore useful for representing complex systems with strong influences from social and economic elements (Xu *et al.* 2002). Greater transparency is achieved with participant interaction during model co-production and experimentation with model outputs (Winz *et al.* 2009). In these later stages of model testing, simulation experiments provide immediate feedback to the participants, and can suggest new data to collect and new scenarios to run; resolve uncertainties, foster consensus and improve the overall model structure (Sterman, 2001; Stave, 2003).

Modern system dynamics software employs graphical user interfaces that make it possible for those with little or no technical expertise to quickly sketch a causal diagram that captures time delays, feedbacks, stocks and flows. Unlike Bayesian networks, no simplification is required to make problems mathematically tractable (Winz *et al.* 2009).

Focussing on modelling a specific problem and the system structure that generates it (rather than the whole system) guides participants to explore problem causes before discussing general, strategic-level policy options. It further enables leverage points to be identified. These are variables to which the system is highly sensitive, and which effect system changes when they themselves are modified. Identifying these levers can help participants to focus on the critical internal factors, rather than devoting time and resources to external causes over which they have little control (Stave, 2002).

Finally, system dynamics efficiently model the interventions whose effects are delayed in time, and can provide an early indication to decision-makers that sufficient corrective action has been taken (Sterman, 2001).

5.2.2 Limitations of system dynamics

System dynamics has the following notable limitations:

1. Lack of predictive capabilities

   System dynamics models are less useful for making exact predictions about future system states, than for indicating how making different choices might alter the tendency to move towards a particular state (Nandalal and Simonovic, 2003). Following their modelling of the Middle Rio Grande, Tidwell *et al.* (2004) found that treating the model as a predictive tool caused concern among participants, who were more comfortable using it as a means to visualise the problem (and its potential solutions), so that they themselves became better predictors.

2. Focus on the long-term

   System dynamics is well suited to modelling problems that are governed by feedback and have a long-term time horizon (Vennix, 1996). This focus on the long-term may not align with the needs of flood-risk decision-makers (particularly in the aftermath of a significant event), who are under pressure to find timely and pragmatic solutions (Stave, 2002).

5.2.3 Using system dynamics in a participatory setting

The strengths and limitations of system dynamics in a participatory setting are further explored in Paper I (Section 5.2, pI—19) and Paper III (Section 5.2, pIII—15). In summary, system dynamics models facilitate elucidation of system structure and behaviour through a clear and transparent exploration of how different components of a system are related, a structure whose components can later be modified to enable the simulation of a range of scenarios (Khan *et al.* 2009). In the early stages of model development, causal loop diagrams provide an abstracted but highly accessible graphical mechanism for documenting and communicating the inter-relationships and feedback responses between system variables, before being translated into simulation models (Ahmad and Simonovic, 2000; Sterman, 2001). This coupling of simple graphical interfacing methods with more complex system simulations delivers considerable accessibility for participants with little technical modelling expertise.

Qualitative judgement is required in the definition of model structure and in how different interrelationships in the model are weighted, and this can reduce rigour (Andersen and Rohrbaugh, 1992; Winz *et al*., 2009). However, in the context of participatory modelling, capturing this expert judgement and using system dynamics models as a heuristic means of understanding flood risk, is commonly an important substantive and social outcome.

Finally, systems dynamics models are adaptable in the respect that it is possible to define new parameters and adjust the model structure to test different scenarios without rebuilding the entire model (Sterman, 2001). This adaptability, coupled with the ability to explore the dynamic impacts of these scenarios in real time, offers strong evaluative capabilities (Stave 2002; 2003; Tidwell *et al*., 2004). The ability to explore different future scenarios and evaluate how different interventions might impact upon flood risk, suggest that system dynamics offers potential to support the later stages of the decision-making framework. These stages include options appraisal, decision implementation and review (Figure 1.3, p20).

Challenges facing the use of system dynamics in a participatory setting stem from an apparent ease-of-use, which can mask the intellectual demands of model conceptualisation and model adjustments. In practice, both of these tasks require the support of expert facilitation, which limits the ability of local stakeholders to evolve their own models directly (Ahmad and Simonovic, 2000; Sterman, 2001). This was observed in the Southwell case study, where participants struggled to conceptualise the system in terms of feedback loops, which led to this key system dynamics element being absent from much of the model development process (Paper III, Section 5.3, pIII—16-III—26).

5.2.4 Case study summary: Southwell

Paper III reports on a participatory modelling process in Southwell, Nottinghamshire, which used elements of system dynamics to explore community resilience. The process aimed to support local stakeholders with the evaluation of several community-scale interventions that they had developed, exploring the extent to which each intervention could reduce risk to different receptors at eight flood hotspots across the town. The model was constructed in system dynamics software Goldsim, using the temporal aspects of the technique to investigate how flood risk changed as a result of changes in flood water depth experienced during a recent flooding event. It consisted of five evening workshops, flanked by pre- and post-project interviews.

Southwell, Nottinghamshire was significantly affected by surface water and fluvial flooding in July 2013, following an intense convective storm. After the event, which resulted in the flooding of over 200 residential properties, the community began to take a more proactive role in flood risk management, establishing Southwell Flood Forum to act as a 'representative voice for [the] community and …[to] work in partnership with the Agencies and Authorities whose work involves flood risk' (National Flood Forum, 2016). Researchers from the University of Nottingham partnered with Southwell Flood Forum, and used elements of system dynamics to co-produce a model of the local flood risk system, with the aim of

exploring how different community interventions, either active or planned, might reduce the exposure and vulnerability of different receptors (for detailed aims see Paper III, Section 3, pIII—6).

When situated within the decision-making process, the Southwell case study supported Stages 6 and 7, namely making and implementing the decision (Figure 5.6). The study is not considered one of options appraisal, as many of the community options being explored were already in the late planning or early implementation stages. The focus on Stages 6 and 7 place the case study within the wider cycle of decision making (Figure 1.3, p20), where participation offers opportunities for *collaboration* between stakeholders (Figure 1.2, p19).

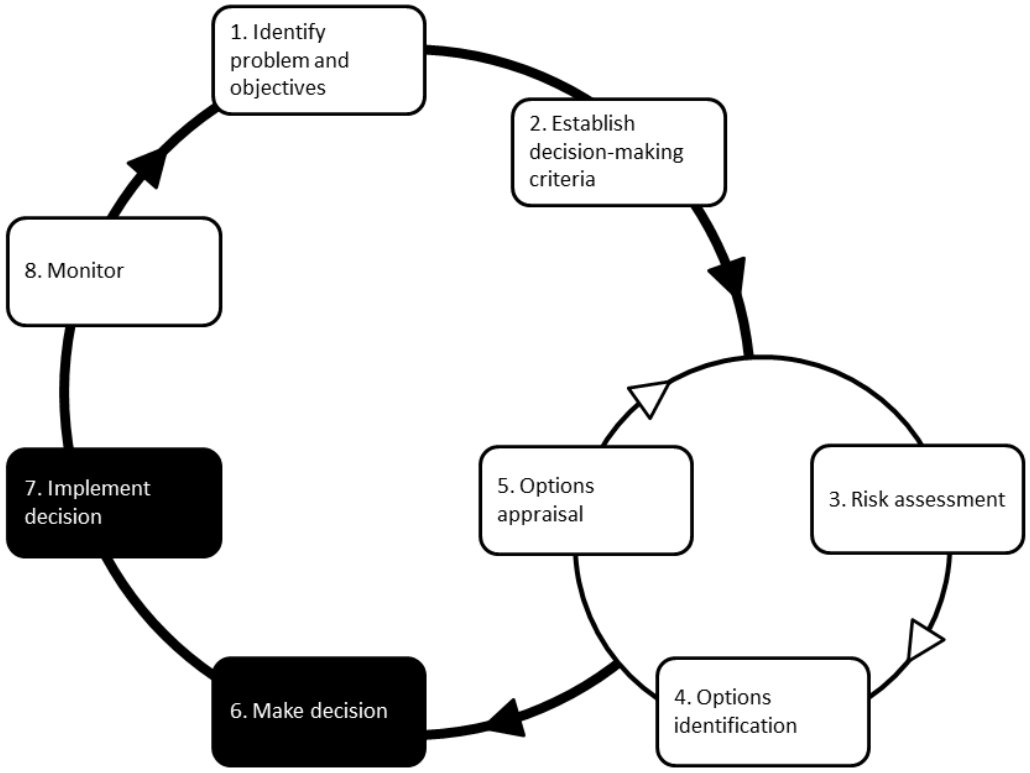


Figure 5.6: Stages of the decision-making process supported by participatory modelling in the Southwell case study (highlighted in black)

6. Evaluation methodologies and rationale

Although the postulated benefits of participation are well documented (Section 3.2, p47), sceptics have warned about taking the romanticised view that participatory processes are automatically more legitimate, democratic and inclusive (*cf.* Haughton *et al.* 2015). While a wide body of literature exists on the evaluation of participatory processes, many studies report on the benefits solely from a normative perspective, while their actual outcomes (from a substantive and instrumental perspective) are possibly more valuable to flood risk management.

The final paper in this thesis, Paper IV, sets out a holistic evaluation framework for participation in flood risk management, providing both criteria for process and outcomes evaluation and using UK case studies to exemplify their relevance and efficacy. Criteria are framed around the key opportunities for participation in local flood risk management, identified in Section 1 (Figure 1.2, p19) and restated below:

1. *Opportunity for collaboration*:

   Active participation facilitates flood risk management to be conducted locally and for interventions to be developed in collaboration with local stakeholders, where those at risk become active participants in risk governance.

2. *Opportunity for capacity-building:*

   Active participation fosters the building of capacity at the local level, acknowledging new sources of knowledge and expertise, particularly with regard to non-structural responses, the management of surface water, flood recovery and insurance.

The aims of Paper IV are to outline a framework for evaluating participation in flood risk management by exploring the dimensions and determinants of effectiveness (Young, 1994), and to populate that framework with practical criteria that allow users to conduct a consistent evaluation bespoke to flood risk. This paper directly addresses Research Question 4 (p25) in addition to providing evidence to support claims made for Research Question 3 (*ibid.*), although it is appreciated that these are limited to those stages in the decision-making process (Figure 1.3, p20) to which the specific cases apply. Further research, applying different participatory modelling techniques in different contexts, will add to this body of evidence, provided that evaluation is undertaken in a holistic manner.

The framework presented in Paper IV critically differs from many traditional evaluation frameworks that focus on process evaluation, arguing that for an evaluation to be holistic, it should include four key evaluation elements: context, process, substantive outcomes and social outcomes (Figure 6.1). This holistic evaluation meets the need to think differently about how participatory processes are evaluated,

particularly in the field of flood risk management. It has been demonstrated that flood risk management is a multi-stage decision-making processes, where local stakeholders are encouraged to participate in a range of activities (see Figure 1.3, p20 and Table 2.3, p44). Within the range of stakeholders there will be an array of (potentially conflicting) views about how to manage the flood risk system, in addition to a range of success (or 'effectiveness') metrics (many of which could be delayed in time and/or social in nature) (Paper IV, Section 2, pIV—5). This requires an extension of evaluation to encompass both substantive and longer-term social outcomes alongside traditional measures of process effectiveness.

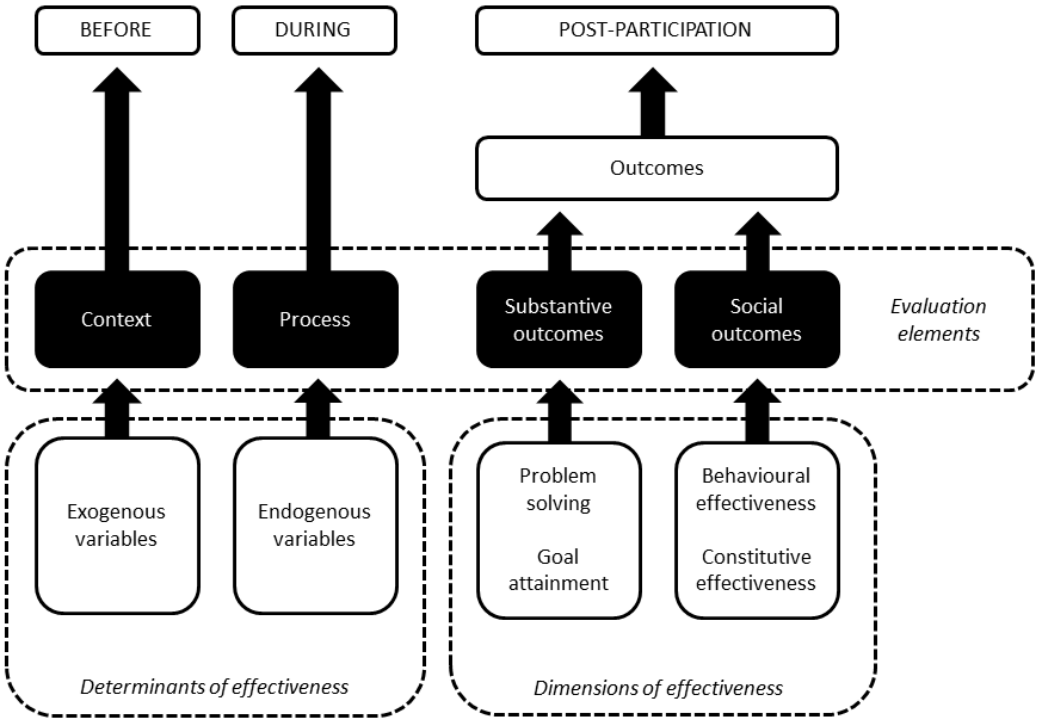


Figure 6.1: Framework for evaluating the effectiveness of participation in flood risk management

6.1 Context and process evaluation

The framework uses Young's (1994) 'determinants of effectiveness' to frame an evaluation of the context and process elements (Figure 6.1).

The evaluation of context is concerned with understanding exogenous variables: structural, contextual characteristics of a locality that are outside of one's immediate control, but whose understanding can be crucial when designing a process that is well-adapted to the context in which the participation is set (National Research Council, 1996). It is argued that criteria for context evaluation include: understanding of the issue; support from officials and community leaders; history of past interactions;

and the complexity of the dispute. These criteria originate in literature that explores the structural variables affecting participation (*cf.* Lampe and Kaplan, 1999; Beierle and Konisky, 2000; Bier, 2001).

On the other hand, process evaluation is concerned with endogenous variables: various internal attributes and properties that can be manipulated by those responsible for designing and managing a process, such that the desired outcomes and objectives are attained. Drawing on Fiorino's (1990) four 'principles of effective participation', Paper IV presents five criteria that characterise an effective participatory process (Figure 6.2). Particular emphasis is placed on the extension of Fiorino's (1990) framework to include quality as a criterion, which focusses on the process characteristics that support the recruitment and retention of participants.

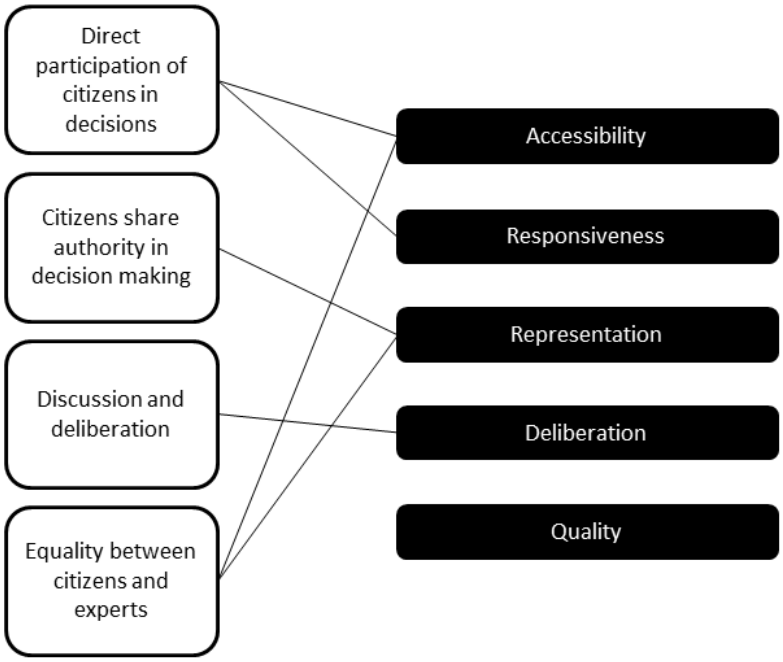


Figure 6.2: Development of process criteria (shaded boxes) from Fiorino's (1990) principles of effective participation (white boxes)

Details of the individual criteria, for both context and process evaluation, can be found in Paper IV (pIV—8-IV—15), which draws on examples from flood risk management in the UK, to examine the relevance of each, and exemplifies how they might be achieved in practice.

6.2 Substantive and social outcomes evaluation

To understand and assess the effectiveness of participatory outcomes, Young (1994) presents six dimensions of effectiveness, of which four are used in Paper IV (pIV—5) to frame an evaluation of substantive and longer-term social outcomes:

1. Effectiveness as problem solving
2. Effectiveness as goal attainment
3. Behavioural effectiveness
4. Constitutive effectiveness

Substantive outcome evaluation is concerned with understanding and monitoring the achievement of user goals, and has various benefits for both participants and facilitators (Paper IV, Section 6.1, pIV—16). Goals are co-produced with those participants responsible for using the outcomes of the process, and the process is subsequently measured against these goals (effectiveness as goal attainment). Benefits of establishing end user goals in the early stages of decision-making include the promotion of *collaboration* by allowing stakeholders to select techniques and activities that are best suited to achieving their collective goals, providing critical information about the degree of consensus between stakeholders, and identifying potential areas of conflict. Revisiting these goals throughout the process helps participants to focus on the problem that motivated the participatory process in the first place (effectiveness as problem solving).

Social outcomes evaluation is concerned with exploring how community resilience has changed and whether it is more or less likely to increase in the future as a result of participation (Paper IV, Section 6.2, pIV—16). It assesses the extent to which opportunities for *capacity-building* have been created, by measuring the likelihood that one or more participants will change their behaviour as a result of participating (behavioural effectiveness); and the likelihood that the number and effectiveness of social practices will increase (constitutive effectiveness). In Paper IV the focus of social outcome evaluation is strongly on assessing the conditions under which social capacity and community resilience is built. It frames community resilience as the result of three interacting social capacities: knowledge exchange, motivation to proactively reduce flood risk, and networking between stakeholders (after Buchecker *et al.* 2013). Taken together, these capacities determine the way in which a community can prepare for, resist the impact of, respond to, and recover from, a flood event (Figure 6.3). The paper goes on to present arguments for why each capacity is important in the field of flood risk management, drawing on UK examples of best practice.

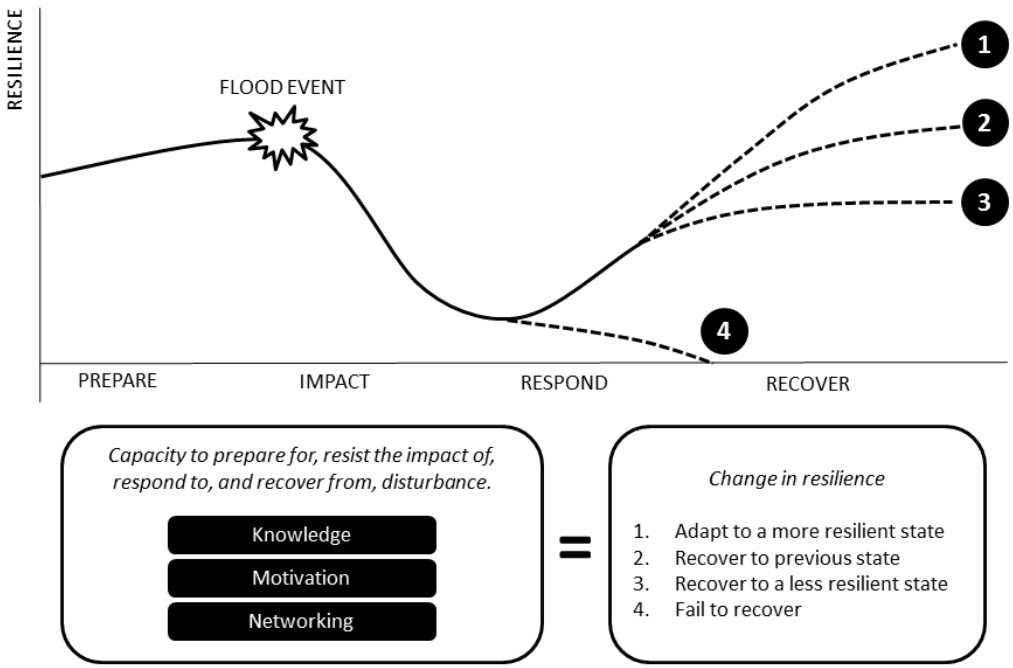


Figure 6.3: Interacting social capacities effecting a change in resilience (modified after Cutter *et al.* 2008; DFID, 2011; Buchecker *et al.* 2013)

I) Paper I.

Doing flood risk modelling differently: a framework for stakeholder participation

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Abstract

While the potential benefits of actively involving local stakeholders in decision-making are well documented, the design and facilitation of effective participatory processes as well as the selection of appropriate techniques remains a challenge. As responsibilities for managing flood risk are being increasingly devolved to a wider range of local stakeholders, participation offers a mechanism for actively involving those stakeholders in decision-making, and utilising their unique situated knowledge. This paper outlines a structured approach to participation, which is sufficiently flexible to accommodate a range of participatory modelling techniques. It goes on to identify five requirements flood risk management might seek from participation, and uses these as a platform from which to critique three popular participatory modelling techniques. Through this targeted review, strengths and limitations of each technique are identified, which form the beginning of a framework for identifying which technique might be the most likely to be effective in any given flood risk context.

Highlights

- Participatory modelling championed as complementary to traditional methods
- Approach can redress balance between likelihood and consequences
- Five requirements of participation, specific to flood risk, are identified
- Strengths and limitations of three widely-used techniques are explored
- Importance of evaluating both process and outcomes is highlighted

Keywords

Participatory modelling, stakeholder involvement, flood risk, risk governance, stakeholder analysis

1. Introduction

Flood risk management is unique in environmental management. Arguably more so than in any other field, those tasked with managing flood risk work at the interface between those receptors at risk from flooding, and the pathways through which they are exposed to the hazard. This interface is broad, with receptors and pathways that are often closely coupled, resulting in a complex system with many interrelated variables. This complexity results in a variety of individuals and organisations that identify themselves as stakeholders, and a wealth of potential mechanisms to reduce risk.

As responsibilities for managing flood risk are increasingly devolved to the local level and those at risk are increasingly expected to take an active role in its management, agencies are seeking ways of working with these local stakeholders as a means of finding efficient and sustainable solutions (Rhodes, 1997). Under the pressures of personnel and budgetary reductions, it is critical that agencies are selective about which problems they model, which solutions they explore, and which they eventually adopt.

This paper presents a framework for involving stakeholders in flood risk management, in response to two challenges that arise from these arguments:

1. ACCESSIBILITY CHALLENGE – low-complexity techniques are sought which make flood risk management accessible to local stakeholders, some with little or no technical expertise.

2. COMPLEXITY CHALLENGE – these techniques must be able to structure knowledge about a complex system, and capture the interrelationships between system elements.

It goes on to explore three popular participatory modelling methods, namely Bayesian networks, system dynamics, and (fuzzy) cognitive mapping; which present distinct opportunities and challenges when used in a flood risk management context.

Research in Pickering, North Yorkshire, UK has demonstrated the effectiveness of actively engaging local stakeholders in flood risk modelling, and harnessing the tacit, local knowledge that they possess (Lane *et al.*, 2011; Ryedale Flood Research Group, 2008). Whilst the example is commonly heralded as best-practice local flood risk management, utilising knowledge co-production to develop innovative context-specific solutions; many communities wishing to benefit from participation lack the extensive resources and academic input provided to Pickering. Thus, widespread efforts to access and represent stakeholder knowledge alongside expert knowledge remain limited, resulting in participation that is limited to consultation, and potentially damaging (RELU, 2010). This hesitancy to engage is arguably a result of the lack of advice about what a more 'active' participatory process should look like, how it might be organised, and what techniques might be employed to facilitate it. The time and financial

costs of implementing participation processes can be substantial, increasing the consequences should a process fail.

2. Stakeholder participation in flood risk management

Over the last two decades national, regional and international legislation has increasingly stipulated greater participation in decision-making processes, which extends beyond traditionally-practiced consultation, and is present in every level of society. International-level policies including the Rio Declaration (UNEP, 1992), United Nations Agenda 21 (UNCED, 1992), Aarhus Convention (UNECE, 1998) and the Dublin Statement on Water and Sustainable Development (ICWE, 1992) imply that active participation in flood risk management should be operating at local scales, bringing 'decision-making as close as possible to those affected' (ICWE, 1992:19).

Flood risk management is moving beyond finding solutions and providing emergency response, towards more integrated models that stress prevention and preparedness. This model departs from the traditional view stressing the primacy of scientific knowledge, and appreciates the importance of understanding how the public perceive and construct concepts of risk (Jasanoff, 1998; Dooge, 1992). Reasons for recent changes in risk management include developments in social science which have shunned the information-deficit model (communication from a source of authority to an audience deficient in understanding) in favour of two-way dialogic communication in which both experts and non-experts each accept the limits of their own knowledge, and value how, when taken together, both can be complementary (Höppner *et al.* 2010). Secondly, there has been a move to restore trust in public bodies, which was eroded throughout the 1980s, partially in response to a series of regulatory scandals (e.g. BSE, GM food, dioxine) (Lofstedt, 2004). Finally, the rise of the sustainability paradigm has opened up the field of risk management to a wider range of actors, creating new spaces for interaction and deliberation (*cf.* Healey, 1993).

The European Union provides a salient example in which flood risk governance moved downwards (towards local decision-making) and outwards (involving shared responsibilities) during the 1980s and 1990s, with a formerly linear chain of command being replaced by a complex structure of networks linking multiple layers of society (Rhodes, 1997). Despite this downward distribution of power, the European Union has become more involved in the governance of flooding and other natural hazards, through policy documents such as the Water Framework Directive (EC, 2000) and Floods Directive (EC, 2007) that promote and guide participation at the local level. In the UK, strategies such as those outlined in 'Making Space for Water' (DEFRA, 2004), have shifted responsibility onto other sectors of society, for example by encouraging householders and businesses to make their buildings more resilient to flooding.

Steinführer *et al.* (2009) term this the 'privatisation of risk', a process whereby those at risk are transformed into risk managers and active participants in risk governance.

Meeting the *accessibility* and *complexity* challenges outlined in Section 1 requires modelling to encompass both flood consequences and perceived risk, utilising the tacit knowledge that exists amongst local residents with experience of past flooding events and its effects. This tacit knowledge is often fragmented and dispersed. Participation is tasked with collating, structuring and re-presenting that knowledge in a way that is meaningful to practitioners, such that it can contribute to the identification of options. Actively involving local stakeholders in options identification ensure that the detailed appraisal that follows addresses problems salient to the local community; and results in interventions that are appropriate, sustainable, and have broad public support.

3. Participatory modelling

Participatory modelling encompasses both a number of mechanistic approaches and practical techniques for planning, developing and applying a model with those people whose community is under study (for reviews see Lynam *et al.* 2007; Renger *et al.* 2008). Popular approaches include, *inter alia,* group model building (Vennix *et al.* 1990; Richardson and Andersen, 1995), companion modelling (CIRAD, 2004), mediated modelling (van den Belt, 2004), participatory simulation, shared vision planning (Werick and Palmer, 2004) and collaborative learning (Voinov and Bousquet, 2010). While there are subtle differences between these different approaches, they all share fundamental similarities. They scaffold the open-ended exploration of issues, problems and objectives (Mendoza and Prabhu, 2006), attempting to maintain scientific rigour, whilst being accessible to local stakeholders who are often unfamiliar with the technical knowledge or experience needed to construct and/or use traditional models.

These approaches therefore have significant potential to meet both the accessibility and complexity challenges outlined in Section 1, and to be used to develop conceptual models of flood consequences that inform numerical models of flood likelihood, whose technical complexity limits inclusive participation. Local stakeholders are often closely acquainted with the environment, and can offer information at a level of detail and complexity rarely seen in computational models (Prell *et al.* 2007). It is not suggested that these conceptual models will replace numerical models, but rather complement each other, both providing evidence to inform options identification and appraisal (Figure 1).

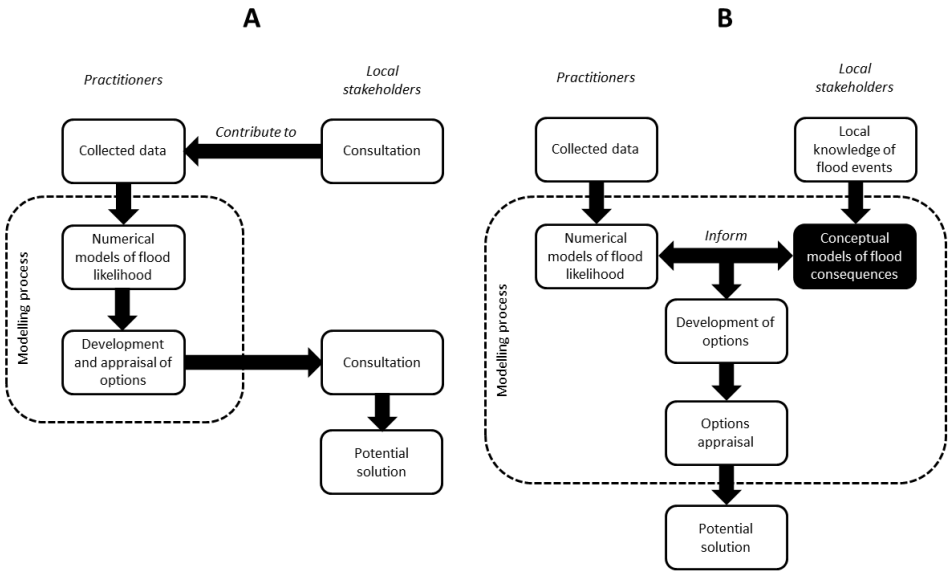


Figure 1: Schematic showing how current flood risk management processes (A) might be modified to more actively involve local stakeholders in modelling (B)

3.1 Benefits of participatory modelling

The challenges set in Section 1 can be mapped onto the normative and pragmatic claims made by proponents of participatory modelling to provide an indication as to what the approach might offer flood risk modelling (*cf.* Reed, 2008). From these claims, five qualities are identified (Figure 2), with further information provided on each in Table 1.

The *accessibility* challenge is met through the realisation of normative claims. Accessibility is achieved by making it possible for local stakeholders, regardless of their technical expertise, to be actively engaged in the development and evaluation of models. A secondary normative claim argues participatory modelling offers greater transparency*:* involvement of local stakeholders allows the sharing of tacit knowledge and open discussions about the reliability of data and knowledge sources, thus increasing stakeholder trust in decisions and the decision-making process (Jasanoff, 2003; Evans and Plows, 2007).

The *complexity* challenge is met through the realisation of pragmatic claims. These claims assert that participatory modelling is *adaptable:* sufficiently flexible to represent the local context; able to develop interventions that are bespoke to local cultural, social and environmental conditions; and easily updated as new information becomes available. Second, participatory modelling fosters *evaluation*: with stakeholders exploring future scenarios and building consensus over preferred options, leading to lasting support and fostering a sense of ownership. Finally, it is *holistic:* structuring and representing knowledge from both physical and social sources, and integrating both quantitative and qualitative data, enabling higher quality decisions by widening the knowledge base (Bulkeley and Mol, 2003; Reed *et al.* 2009).

Figure 2: Claims and qualities of participation

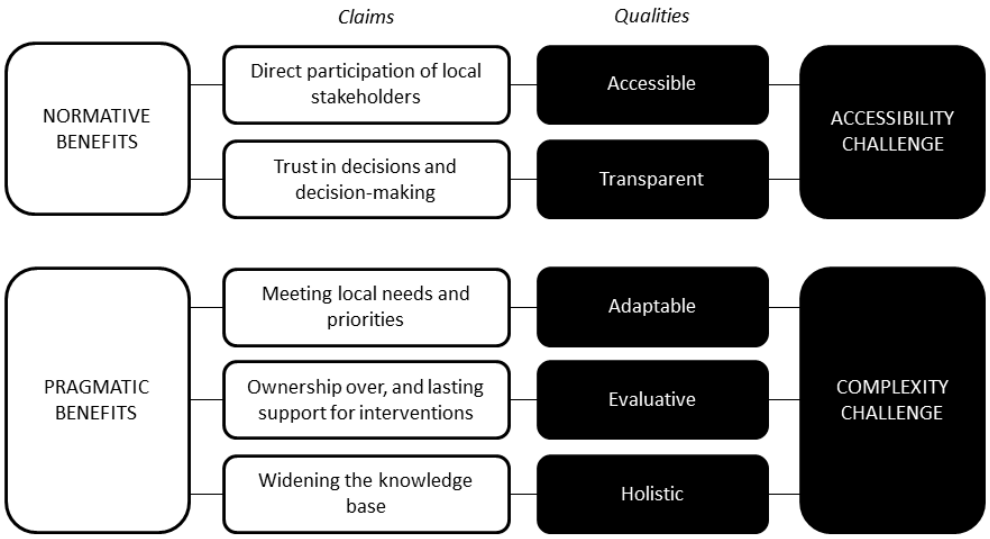


Table 1: Potential benefits for flood risk management

Key quality	Potential benefits for flood risk modelling
Accessible	The ability to enable a wide range of stakeholders to be involved in the development, evaluation and refinement of flood risk models. Interfaces are simplified – possibly graphical - and knowledge is represented conceptually. Methods used to structure knowledge have low complexity.
Transparent	The ability to quantify and communicate the impact, limitations and uncertainties associated with different potential decisions and actions. Knowledge representation is sufficiently clear that it can be traced, along with the reasons behind different outcomes.
Adaptable	The ability to encapsulate the specific realities and dynamics of local flood contexts and be readily updated as more knowledge is acquired and/or as social and hydrologic systems change. Methods by which knowledge is structured support easy adjustment and extensibility.
Evaluative	The ability to facilitate the exploration of scenarios and direct stakeholders and decision-makers towards consensus about preferred options. Re-instantiation and / or recalibration of knowledge representation is straightforward.
Holistic	The ability to incorporate and integrate a broad knowledge base – including physically and socially-derived information. Holistic tools will also be able to support the structuring, representation and integration of knowledge as both quantitative and qualitative data.

4. Participatory approach

A three step approach is presented in which different participatory modelling techniques can be embedded (Figure 3), which is broadly reflective of the generic steps adopted in many environmental modelling tasks (Jakeman *et al.* 2006).

Stage 1: A coupled stakeholder-led development of shared flood risk objectives and analysis of stakeholders with the situated knowledge necessary to inform the modelling process.

Stage 2: Modification of the approach and selection of a modelling technique that is suited to meeting the participant group's shared objectives. The co-production of a conceptual flood risk model depicting stakeholders' shared understanding of the local flood risk system and the interactions between its components.

Stage 3: Testing and validation of the model to explore future scenarios and assess the impact that applying different interventions (and combinations thereof) has on the group objectives; resulting in a set of recommendations for wider dissemination.

Running alongside the process elements are a sequence of complementary evaluative elements that are explored in Section 6.

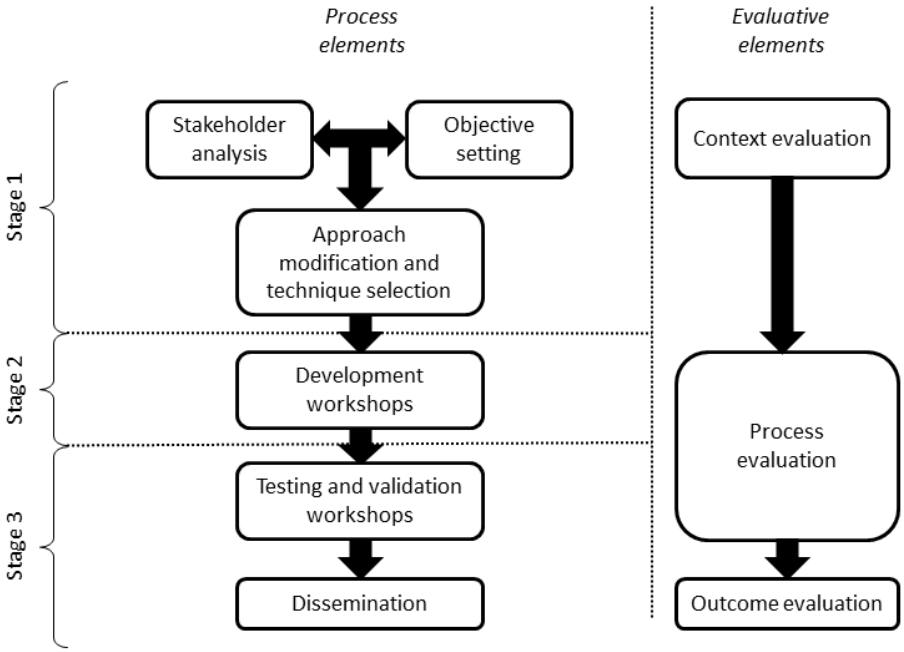


Figure 3: Stages in the participatory approach

4.1 Stage 1

The outcomes of any participatory process will necessarily be shaped by the knowledge, experience and expertise of those participating. Effective stakeholder analysis during the early stages of a process can minimise the marginalisation of groups, ensure all views are represented, and afford the process greater legitimacy (Reed *et al.* 2009). The process of selecting and prioritising stakeholders further provides an opportunity for the facilitators to formulate a clear definition of the problem, and the objectives that are of importance to the local community.

Ultimately, a technique will be selected that best meets community requirements. Understanding community motivations for engaging with participatory modelling will support process facilitators with technique selection by highlighting the extent to which they value each of the five qualities (Table 1). For example, a community in the early stages of options identification may be interested in applying a technique that is particularly effective at identifying variables driving the system, and where they believe interventions might be employed to maximise the chance of achieving their objectives. In this case, a group might seek a technique that is both *holistic* and *adaptable*. Alternatively a community that seeks to use participation to support options appraisal may value the ability to compare different interventions, and how these impact upon their objectives (i.e. one that prioritises *evaluation*).

4.1.1 Stakeholder analysis

Stakeholder analysis aims to prioritise individuals or groups for participation, and is used, *inter alia,* to understand the range of potentially conflicting stakeholder interests (Friedman and Miles, 2006; Prell *et al.* 2007). It is a pragmatic reality that those managing a participatory process cannot attend to all potential claims, giving rise to the argument that stakeholders must be identified, and later prioritised, according to certain attributes that they possess. Several techniques exist for stakeholder identification (*cf.* Bryson, 2004), sometimes employing further iterative discussions with pre-identified individuals to reveal unknown stakeholders, commonly termed 'snowball' or 'referral sampling (Hair *et al.* 2000).

Prioritising who participates can be challenging and is often achieved by differentiating between, and categorising stakeholders, using either top-down 'analytical' or bottom-up 'reconstructive' methods (Drysek and Berejikian, 1993). Analytical methods are carried out by those conducting the analysis and usually involve using matrices or Venn diagrams to map stakeholders according to a range of desirable attributes (*cf.* Eden and Ackermann, 1998; De Lopez, 2001). The main limitation is that analytical techniques tend to identify the 'usual suspects', prioritising more powerful stakeholders; and risk the under-representation of marginalised groups (Grimble and Chan, 1995; MacArthur, 1997). Reconstructive methods allow these categorisations to be derived from the stakeholders themselves,

resulting in an analysis that more closely reflects their concerns (Hare and Pahl-Wostl, 2002). Limitations of reconstructive methods include the impractically large number of stakeholders identified, and potential shifts in the focus of the participatory process, which may be desirable or may not (Reed *et al.* 2009).

4.1.2 Stakeholder analysis for participation in flood risk management

Several characteristics of flood risk management make it particularly appropriate for the application of stakeholder analysis: multiple actors with complex interrelationships; unclear or shared responsibilities; differing viewpoints and priorities; limited resources with which to address the issue; and the need to successfully implement policy within a social environment.

Traditionally participation in flood risk management has taken a paternalistic model with only two types of stakeholders: those with responsibility for decision-making and those with applicable scientific expertise (scientists and engineers) (Glicken, 2000). However, contemporary flood risk management increasingly seeks a wider range of inputs, including cognitive (scientific/technical expertise), and tacit (local/personal experience) knowledge. To accommodate this needs, and appreciating that those with responsibility are not always those with expertise, we suggest a modification of the Mitchell *et al.* (1997) typology, driven by three stakeholder attributes: responsibility, expertise and affection (Figure 4).

Stakeholders possessing *responsibility* have an obligation, by way of their job or role, to reduce flood risk in a specific area. Responsible individuals do not necessarily have flood risk expertise (e.g. local government, elected officials), and may not be directly affected by flooding. Those with *affection* are those directly affected by flooding. Some of these individuals will hold a position of responsibility (e.g. chair of flood action group), and some will have high levels of (usually experiential) expertise (e.g. retired professionals). Finally those with *expertise* have specialist knowledge, experience or understanding of the flood risk issue, either local or general. The typology accommodates the move towards valuing both technical and tacit knowledge by explicitly recruiting both *expert practitioners* (Sector 3) and *expert locals* (Sector 2). By identifying the stakeholders that exhibit two or more of these attributes, a social space is created from which to recruit stakeholders that can effectively contribute to a participatory process (shaded area in Figure 4).

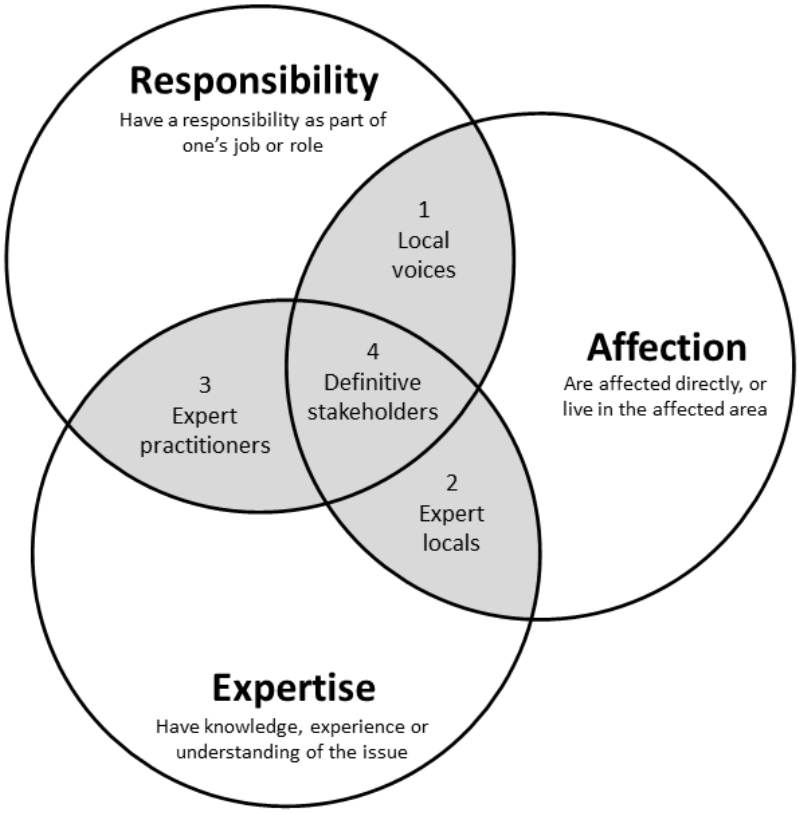


Figure 4: Stakeholder typology (after Freeman, 1984; Mitchell *et al.* 1997)

There are likely to be few stakeholders that possess all three attributes. The term *definitive stakeholder* is borrowed from Mitchell *et al.* (1997) to describe these stakeholders. Recruiting a representative group of potential participants, however, requires extension further out in the diagram, to include those stakeholders exhibiting any two of the three attributes (shaded area in Figure 4). We here use the terms local voices, expert locals and expert practitioners to describe these stakeholders (Table 2).

Table 2: Essential stakeholder groups for participation in flood risk management

Stakeholder group	Description
Local voices	Stakeholders with both responsibility and affection (but not expertise). These stakeholders may be those in local government or other elected roles that can speak on behalf of the local community. Having been affected directly by the issue adds credibility to their involvement and their views. They are likely to have many ties to others within the local community, and will be effective disseminators of information. Having the support of these stakeholders will help to ensure that any flood risk interventions are successful by engendering lasting community support.
Expert locals	Stakeholders with both affection and expertise (but not representation). These are stakeholders who, through living in the area or experiencing flooding first hand, possess experiential knowledge of the issue. They will bring to the table much of the non-scientific and context-specific knowledge that is required to design successful interventions. By working together with expert practitioners they can help to design interventions that are both technically feasible and socially acceptable.
Expert practitioners	Stakeholders with both expertise and representation (but not affection). These stakeholders possess technical expertise and hold a role where they are (at least partially) responsible for managing flood risk. These will include employees of local and regional government, environmental regulators and water utilities, who have specific responsibilities for flood risk management. They will inform the stakeholder group about what is technically feasible, and support the conversion of values into practical options (Glicken, 2000).

4.2 Stage 2

At this stage, participants use the modelling technique/s selected in stage one to construct a conceptual model of the flood risk system as they understand it to function, structured upon the causal relationships that participants understand to exist between system variables. Participants start by defining the system space that they wish to model, referring back to the objectives they set in Stage 1.

The process that follows consists of a series of interactions with participants, following a preformed plan, yet designed to be rethought and adapted to meet participant needs (Barreteau *et al.* 2010). Discussing the content with participants prior to these interactions is widely practiced (Walker *et al.* 2006; Etienne *et al.* 2008). This information, designed to guide participants through the process should outline any differences in levels of involvement, the purpose of each interaction, and where each interaction fits into the overall structure. It is inevitable that the plan will evolve as stakeholders begin

to mould the process to their needs and expectations. With this in mind, stakeholders need to be kept informed on changes to the process design by means of regular debriefing and evaluation sessions.

Although to some extent dependent on the technique chosen, participants will generally work through a process of variable identification, classifying variables by their type, or location in a model structure template. For example, a participant group may classify variables into interventions, objectives and factors; each type playing a different role, and occupying a different location in the model structure. Classifying the variables in such a way will guide participants with the next model development step, which involves organising variables into a cause-effect structure, and identifying the relationships between them. The scripts and rules for accomplishing this task will vary by technique, but the end result is a conceptual model of system functioning and dynamics.

During model development, there will be a number of iterations during which the model structure is revised and improved to better reflect participants' understanding. The amount of time spent iteratively developing the model will depend largely on the contact time available. While iterative development is a key feature of participatory modelling approaches, it is envisaged that as model construction progresses, changes will become less structural in nature. Modelling techniques able to accommodate changes at any stage in the process are considered the most adaptable.

Although software is becoming more user-friendly and intuitive, most techniques will require the facilitator and/or modelling team to do much of the technical work behind the scenes (i.e. between interactions) (RELU, 2010). This reduces the time commitment required from participants, but introduces the risk that the model becomes a black box, where only those involved in the technical work know how the model was constructed, its limitations and uncertainties. Frequent communication can help keep participants informed of progress, and demystify the modelling process. Providing opportunities for the participants to experiment with and test the model in Stage 3 further helps them to grasp how it works and how it was built. Modelling techniques with intuitive and user-friendly software interfaces afford the greatest accessibility.

4.3 Stage 3

At this stage, the model is presented back to the participants as a functioning prototype. As mentioned earlier, participants should be encouraged to engage in orientation tasks to familiarise themselves with the software features. Supporting stakeholders through the most common tasks involved in building/altering the model will provide them with the skills and confidence to continue to use the model after the facilitator and their team have left. This might include installing and opening the model

on a personal computer; adding and removing variables; and creating new or modifying existing relationships.

The primary aim of Stage 3 is to involve the participants in model testing and validation. The objectives of this activity are to check that the behaviour of the final model conforms to the expectations of the participants; enable the identification of any erroneous model behaviour; and make any final adjustments to relationships or variable nodes. Practically, this will involve participants making predictions about how they believe certain interventions and/or factors will affect their objectives, and then testing those predictions in the model. Moving from testing interventions/factors in isolation to testing combinations of different interventions, this activity becomes akin to scenario analysis. Introducing different future scenarios, based for example on governance style, socio-economic conditions, or policy, allows participants to group interventions more easily and ground them in reality.

5. Participatory techniques

Several participatory modelling techniques exist that can be used to structure participants' system and causality knowledge so that the implications of changes under different conditions can be explored. In the case of flood risk modelling, it is the combined understanding of cause and effect in hydrologic, hydraulic, social and infrastructure systems that must be represented. Thus, techniques offering obvious potential are those that have emerged from causality and systems modelling, *inter alia,* systems dynamics models (Forrester, 1961), causal loop diagrams (Sterman, 2001), fuzzy cognitive mapping (Harary *et al.* 1965; Axelrod, 1976) and Bayesian belief networks (Pearl, 1985; 1988). Three of these techniques are reviewed here, with reference to their ability to deliver the five qualities of participation (Table 1) and ultimately achieve the challenges identified in Section 1.

5.1 Bayesian networks

Bayesian networks are a special case of graphical causal model, consisting of a directed acyclic graph (i.e. where no directed path forms a closed loop), with relationships between variables defined using conditional probability (Pearl, 1985; 1988). They have been applied to a range of environmental systems (for a review see Aguilera *et al.* 2011).

If we consider the convergent graph structure shown in Figure 5, we read that nodes A and B are conditionally independent of one another, and that C is conditionally dependent on both A and B. In transforming this into a Bayesian network, estimating the prior probabilities distributions of P(A) and P(B) as well as the conditional probability P(C|A,B) (probability of C given A and B) is required. To simplify the estimation of these, the variables A, B and C are given distinct states allowing

characterisation of the continuous probability distributions through a discretised conditional probability table.

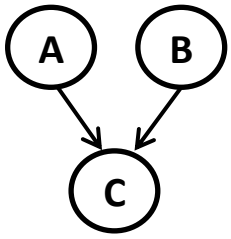


Figure 5: Convergent graph structure

Once the conditional probability table has been constructed to show the probability of each state of C given all possible combinations of its parents (A and B), then the Bayesian network is complete and the propagation of information through it can now be used to see how observed conditions or decisions made (hereafter 'evidence') can affect the probable conditions at other nodes.

For this example, let both A and B have two states, *a1*, *a2*, *b1* and *b2*. Back propagation of evidence through the Bayesian network is described by Bayes' Theorem (Equation 1).

$$P(a1, b1|c1) = \frac{P(c1|a1, b1).P(a1, b1)}{P(c1)}$$

Equation 1

Bayesian networks offer a number of strengths:

1. The encouragement of whole system thinking and understanding
2. The scope for bottom up (diagnostic) and top down (exploratory) reasoning
3. The ability to work with the best available (often scarce or missing) data
4. The ability to combine knowledge from a range of different sources
5. The explicit treatment and communication of uncertainty and risk

These map onto the five qualities of participation as indicated in Figure 6.

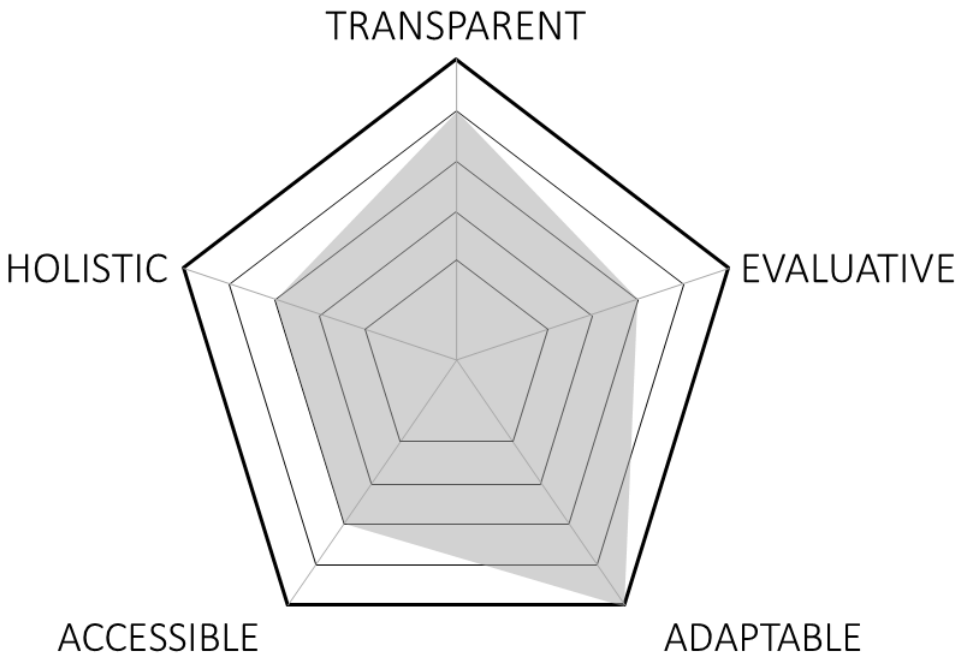


Figure 6: Strengths of Bayesian Networks

The ACCESSIBILITY challenge is primarily achieved though the systematic treatment and clear representation of uncertainty. Both the conditional probability tables and variable state ranges describe the uncertainty at each node, and in solving the network one sees how that uncertainty is propagated through to the final outcomes (*cf.* Marcot *et al.* 2001). In doing so, Bayesian networks can estimate uncertainty more accurately than models which produce mean values as outputs (Aguilera *et al.* 2011). Sensitivity analysis helps to prioritise interventions and knowledge gaps, by identifying both the areas of greatest uncertainty and those that have the greatest influence on stakeholder objectives under different assumptions (Sendzimir *et al.* 2007). These strengths add to the *transparency* of the technique.

The structure of Bayesian network models allows for two main technical strengths that together support achievement of the COMPLEXITY challenge: two-way reasoning and local updating. Reasoning may be conducted both from the bottom-up (exploring the likely causes given evidence on the outcome) and the top-down (exploring the likely outcome given evidence on the inputs, either by intervention or through evidence on their states) (Castelletti and Soncini-Sessa, 2006). The second strength lies in the ability to locally update the network as new data or knowledge becomes available. This is possible because the values underlying each node are independent of the values underlying others nodes. Algorithms such as expectation maximisation allow this process to be automated, with the model using case data to calibrate conditional probability tables (*cf.* Marcot *et al.* 2006). These strengths make Bayesian networks particularly *adaptable* to the needs of local flood risk contexts.

Table 3: Limitations of Bayesian Networks

Limitation	Description
1. Supporting feedback loops	The acyclic nature of Bayesian networks does not support feedback loops, making representation of spatial and temporal dynamics a challenge. Introducing time steps to overcome this is possible, but quickly causes networks to become intractable. On occasion networks are coupled with other simulation techniques that support feedback (Marcot *et al.* 2001; van Kouwen *et al.* 2008; Aguilera *et al.* 2011).
2. Handling of continuous data	In general, Bayesian networks were developed for discrete random variables. However, most available data are continuous or hybrid, and though these data can be handled by Bayesian networks, restrictive limitations apply (van Kouwen *et al.* 2008). The most common solution is for continuous variables to be discretised, which implies a loss of information and can lead to finer relationships being masked. Restricting the number of intervals (states) for computational savings (see Point 3) can further diminish the effect of complex empirical distributions (Uusitalo, 2007). More complex new mathematical solutions have been proposed for handling continuous variables, but these are not commonly incorporated into currently available software (Aguilera *et al.* 2011).
3. Over-reliance on expert opinion	Populating conditional probability tables from a limited number of expert opinions is challenging, particularly in larger models (Landuyt *et al.* 2013). This is often tackled by dividing the model into sub-networks that span a scientific discipline closer in scope to that with which experts are more comfortable working (*cf*. Morgan and Henrion, 1990). Over-reliance on expert opinion in the definition of conditional probability tables may be perceived as subjective or unscientific, reduce model acceptance by policy-makers, and/or lead to misinterpretation or misuse of results (Zorrilla *et al.* 2010). Validation is achieved by comparison with results from different models, independent experts/stakeholder groups, and the literature. Sensitivity testing can help further evaluate the relationships in the network (Aguilera *et al.* 2011).

BOX 1: A Bayesian network model for flood risk options identification

A Bayesian network model (BNM) was co-produced with local stakeholders in Hebden Bridge, West Yorkshire in 2013/14. The project had the aims of determining a set of objectives for reducing flood risk; developing a BNM of local flood risk interventions that represented participants' shared understanding of the local flood risk system; and using that model to explore the impact different interventions (and combinations thereof) had on the objectives.

The following strengths were highlighted:

- Identifying a broad range of potential intervention options, many of which were community-driven social solutions that are rarely integrated into traditional models (adaptable/holistic)

- Relative ease with which both explicit and tacit knowledge can be structured and formalised (adaptable/holistic)

- Ability to reveal misconceptions and gaps in knowledge, as well as offering insights into different participants' perception of risk (accessible)

- Use of the model to explore which intervention options merit further exploration using numerical modelling techniques (i.e. those affecting the greatest positive change in the objectives) (evaluation)

Many simplifications were made to the model as a pragmatic response to maintain accessibility and transparency, including use of binary states, and interpolating conditional probability tables from a subset elicited from stakeholders (see Cain, 2001).

5.2 System dynamics

System dynamics focus on representing the feedback processes that govern the dynamic behaviour of complex systems (Forrester, 1961; Ahmad and Simonovic, 2000). They have been used in environmental management for *inter alia* river basin planning (Palmer, 1994; Palmer *et al.* 1993; 1995; Simonovic *et al.* 1997; Simonovic and Fahmy, 1999); air quality (Stave, 2002); and water resources management (Fletcher, 1988; Stave, 2003; Tidwell *et al.* 2004).

Both qualitative (e.g. causal loop diagrams) and quantitative modelling techniques (e.g. stock and flow diagrams) are employed. Causal loop diagrams describe the system structure, and help participants to generate a dynamic hypothesis that can be formally tested and validated through subsequent simulation (Richardson, 1999; Homer and Oliva, 2001). Stock and flow diagrams describe the condition of the system at a given point in time (stocks); and how fast those stocks are filling or emptying (flows) (Ahmad and Simonovic, 2000). Figure 7 depicts two stocks, A and B, connected by a flow (hourglass symbol), with additional variables (C, D and E) forming two feedback loops that influence the levels of A and B, and the rate of transfer between them. The causal relationships between variables are shown by single arrows and labelled with either positive or negative polarity.

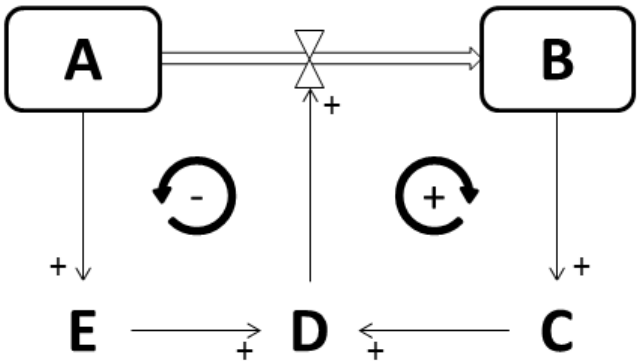


Figure 7: Stock and flow diagram

A positive feedback loop exists from B → C → D → B, while a negative feedback loop exists from A → E → D → A (for examples see Sterman, 2001). When two or more feedback loops interact (as in Figure 7) it is generally impossible to determine dynamic behaviour without using computer simulation, in which the modeller enters parameters and initial conditions, and the model undertakes a number of time steps to iteratively update system variables (Guo *et al.* 2001).

System dynamics offers a number of strengths:

1. The emphasis on system structure as starting point
2. The construction and evaluation of 'what if…?' scenarios
3. Widely available and intuitive software
4. The flexibility of the model structure
5. The incorporation of time delays

These map onto the five qualities of participation as indicated in Figure 8.

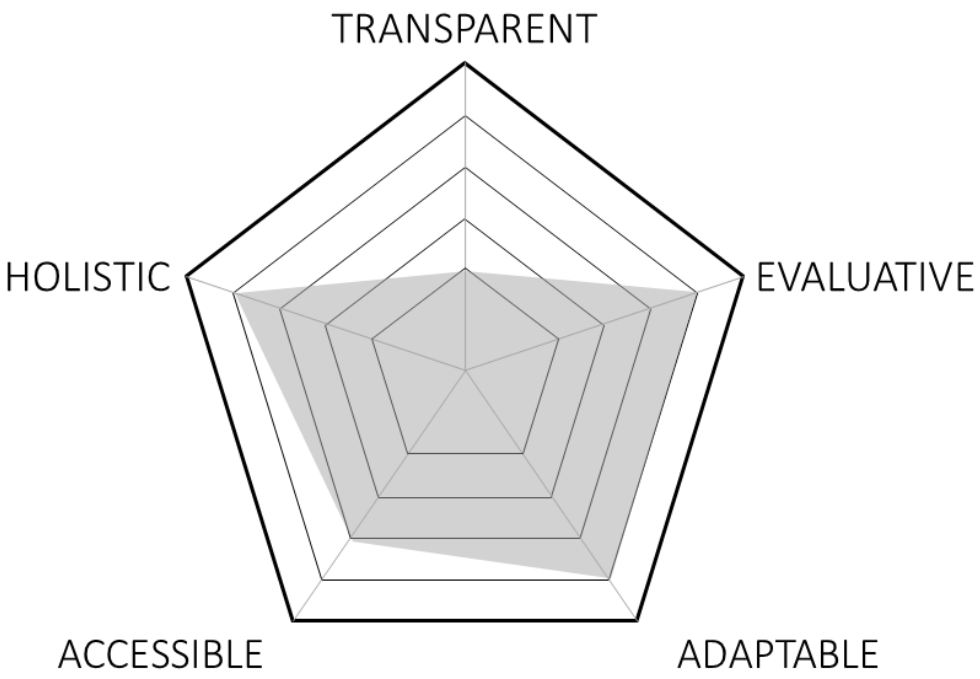


Figure 8: Strengths of system dynamics

System dynamics addresses the ACCESSIBILITY challenges by offering intuitive, widely-available software. Many packages offer extensive user help systems/tutorials, and when supported by effective facilitation, can offer back results within hours (Coyle, 1996). The speed at which results can be obtained enables models to be iteratively improved. Often, the more complex modelling tasks (e.g. sensitivity testing) are largely automated, which adds to their *accessibility* but potentially reduces their *transparency.*

With regard to meeting the COMPLEXITY challenge, a focus on system structure and behaviour from the outset forces participants to think *holistically* throughout the modelling process (Randers, 1973; Winz *et al.* 2009). The technique takes a strategic approach, identifying potential 'policy levers' (areas in the system where they might intervene), rather than focussing on external causes or sources which are more challenging to manage (Stave, 2002). While system dynamics is less useful in making exact

predictions and modelling the specific dynamics of a locality (making it less *adaptable*); strong *evaluative* qualities are offered through scenario testing, that can show how making certain choices alter the tendency of the system to move towards different future states (Nandalal and Simonovic, 2003).

Technically, system dynamics is one of the most *adaptable* participatory modelling methods available (Winz *et al.* 2009). It supports the use of both qualitative and quantitative variables; can consist of nested, cross-scalar models; and be constructed from modules that are able to be interchanged and reused. Furthermore, the ability to support time delays allow models to represent feedback that is not realised immediately; a feature unavailable in techniques such as fuzzy cognitive mapping (Tidwell *et al.* 2004).

Table 4: Limitations of system dynamics

Limitation	Description
1. Social nature of model validation	When a problem is characterised by high uncertainty and complexity, it becomes harder to validate a model by comparing its predictions with observed data. Validation becomes largely a social process, whereby the model structure and its outcomes are evaluated and refined by all involved parties (Barlas and Carpenter, 1990). Structure tests (comparison with experts' mental models); behaviour tests (comparison with real world behaviour) and policy implication tests (comparisons with observed system responses to policy change) can all be conducted to gain confidence in models (Winz *et al.* 2009)
2. Predictive capabilities	Due to the uncertainties in complex open systems, system dynamics modelling cannot provide exact solutions, and is thus poorly suited to addressing well-defined operational problems (Winz *et al.* 2009). Authors found that treating system dynamics models as predictive tools can cause concern amongst modellers and stakeholders alike, while treating them as instructive tools does not (Xu *et al.* 2002; Tidwell *et al.* 2004).
3. Long-term focus	Often, system dynamics is focussed on long-term patterns and trends, while social decisions (including those made by flood risk managers) are plagued by short-term pressures (funding, government policy, staffing, etc…) (Stave, 2002). Participants' goals of finding a quick solution may not align with those of system dynamics modellers, leading to potential tension. Recommended solutions may require structural changes, and revision of objectives and responsibilities; which are often politically unacceptable.

BOX 2: A system dynamics model for developing community flood risk resilience

A conceptual flood risk model using system dynamics elements was co-produced with local stakeholders in Southwell, Nottinghamshire in 2015. The project had the aims of a) identifying the different receptors at risk during recent flood events; and b) to produce a conceptual model to explore how community interventions might be used to reduce the vulnerability and exposure of those receptors. Stakeholders included local residents and members of Southwell Flood Forum (flood action group).

The following strengths were highlighted:

- Key concepts were easy to grasp, however the technique uses a lot of specialist language that required clear explanation early on. Effectively communicating the 'behind the scenes' work supported understanding (accessible)

- Process allowed the community to focus on, and build consensus around, those interventions that would have the greatest risk reduction across the town (adaptable/evaluative)

- Technique effective at bringing together a breadth of different knowledge sources (e.g. personal experiences alongside rainfall data and flood depths) (holistic)

- While the technique could not provide evidence in favour of individual interventions, it engaged stakeholders in discussion about risk hotspots, and allowed Southwell Flood Forum to pass on its key messages to a wider audience (adaptable/accessible)

Some celebrated features of the technique, such as the ability to model feedback, were not employed. While an attempt was made to model feedback by constructing causal loop diagrams, participants' limited technical expertise meant that these mechanisms were not well understood.

5.3 Fuzzy cognitive mapping

Fuzzy cognitive maps (FCMs) are signed fuzzy weighted digraphs, usually involving feedback, which consist of nodes and the directed edges between them (Harary *et al.* 1965; Axelrod, 1976; Kosko, 1986). FCMs have been used for ecosystem management (Ozesmi, 1999; Dadaser and Özesmi, 2002; Hobbs *et al.* 2002); forestry (Skov and Svenning, 2003; Mendoza and Prabhu, 2003; Hjortsø, 2004); agriculture (McRoberts *et al.* 1995; McRoberts and Hughes, 2001); and catchment management (Mouratiadou and Moran, 2007; Kafetzis *et al.* 2010).

A series of nodes represent a collection of concepts C_i linked by causal relationships represented by arrows ($C_i \rightarrow C_{i+1}$). If we consider the divergent graph structure in Figure 9 we see that A is a cause of both B and C. Each concept is given an initial value $\alpha \in [-1, 1]$, and each edge quantified by a weight defining the polarity and strength of the causal relationship between two concepts. These weights can be based on empirical data and/or expert opinion (Hobbs *et al.* 2002).

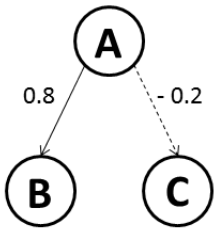


Figure 9: Divergent graph structure

An iterative stabilisation process produces a set of final concept values that can be compared. This analysis must take into account the semi-qualitative nature of how the numbers underlying concepts and weights were derived (Soler *et al.* 2011; Penn *et al.* 2013). Comparing these values provides an indication to the level of importance each concept plays in determining system structure and influencing dynamics (Soler *et al.* 2011). It further provides a basis from which to test the system under different scenarios, often achieved by attaching external drivers to the model and then changing their initial values (*ibid*.).

Fuzzy cognitive mapping offer a number of strengths:

1. The elicitation and management of expert knowledge (especially in data-poor situations)
2. The development of goals and objectives
3. The speed and ease with which maps can be obtained, combined, and evaluated
4. The identification of central (most influential) concepts and/or management actions
5. The ability for feedback processes and evolution over time

These map onto the five qualities of participation as indicated in Figure 10.

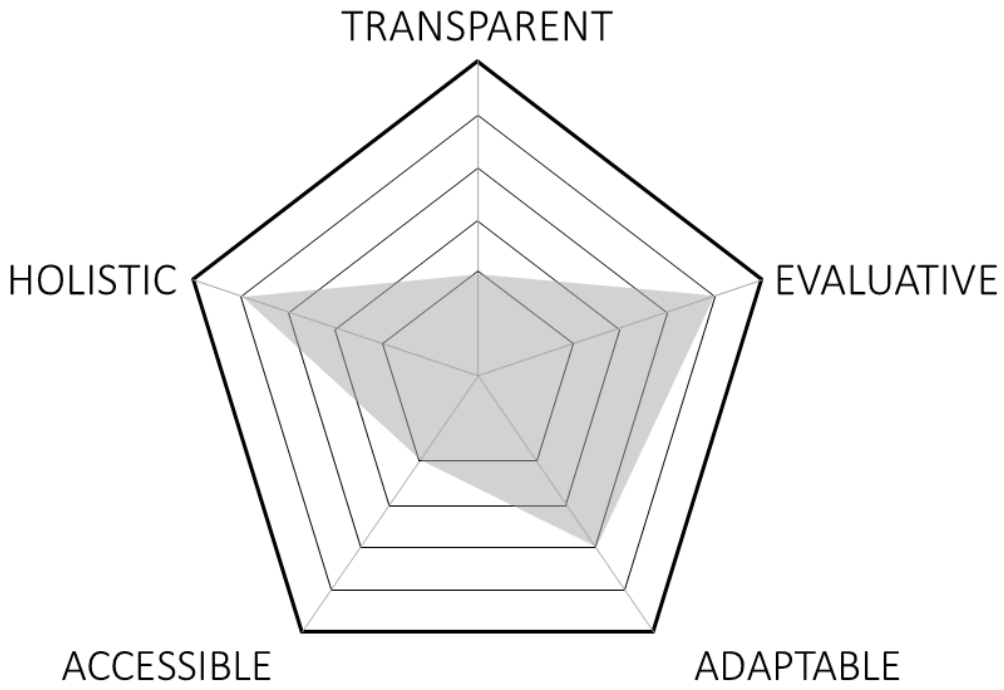


Figure 10: Strengths of fuzzy cognitive mapping

Constructing fuzzy cognitive maps is an intellectually demanding activity that challenges stakeholders to test new ideas, question assumptions, and draw system-level conclusions (Eden and Ackermann, 2004; Hobbs *et al.* 2002). To meet the ACCESSIBILITY challenge, this difficulty is overcome through the use of professional facilitation. With sufficient expertise and support, the basic structure of an FCM can quickly be constructed, permitting the dynamic output of a model to be generated and evaluated at the same meeting (Ackermann and Eden, 2005; Kok, 2009). Finally, the ability of FCMs to self-adapt with increasing data availability can speed up the modelling process, increasing *adaptability* but potentially incurring a loss of *transparency* (Papageorgiou and Salmeron, 2013).

The COMPLEXITY challenge is met through the model structure, ability to combine individual participant maps, and potential to model feedback. The structure of FCMs supports *evaluation* by allowing central concepts to be identified, indicating where interventions, energy and resources might be focussed. Once identified, FCMs can be used to model the variables that drive changes in these concepts, as well as highlighting of the level of group consensus about how they might be managed (Ozesmi and Ozesmi, 2003; Ackermann and Eden, 2005). The ability to produce a composite map promotes *holism* by allowing viewpoints and knowledge bases from different participants to be integrated (Hobbs *et al.* 2002; Khan and Quaddus, 2004). Combining maps allows individuals to make a unique contribution while ensuring that they view their contribution in the wider context, thus facilitating consensus-building and the sharing of goals. Finally the presence of feedback in FCMs adds a temporal aspect that enables the observation of system changes as they unfold, especially when used in conjunction with scenario analysis (Khan and Quaddus, 2004).

Table 5: Limitations of fuzzy cognitive maps

Limitation	Description
1. Risk of over-tuning	FCMs are fundamentally a qualitative technique for capturing expert judgement, with subsequent testing and tuning necessarily a subjective process. This gives rise to concerns over replicability, and introduces the risk of over-tuning the model, such that anticipated values of all outputs are obtained, leaving one in the position where nothing new can be learned from the model (Hobbs *et al.* 2002). This is overcome by not tuning the model to preconceived notions that have little or no empirical foundation.
2. Subjective nature of inputs	Any conclusions drawn from fuzzy cognitive maps must be carefully qualified bearing in mind that they are: a) ultimately based on expert opinion about processes for which there may be little data; and b) based therefore on a restrictive description of the causal relationships. Wherever possible it is desirable to evaluate models by comparison with those built using empirical data, or by consulting a set of independent experts (Hobbs *et al.* 2002).
3. Sensitivity to method selection	Different mapping methods can have a larger effect on the model outputs than changes to the structure of the maps themselves (Penn *et al.* 2013). The literature suggests using multiple techniques and then comparing outputs as part of a wider validation process, to highlight how robust the model outputs are to specific techniques.

4. Identifying individual contributions	Where there are large discrepancies between the individual maps that form the composite map, it can be difficult for stakeholders to recognise their individual contribution to the model (Eden and Ackermann, 2004; Penn *et al.* 2013).
5. Semi-quantified relationships	FCMs assume relationships to be linear and require them to be semi-quantified. However, in many environmental systems relationships are not always linear and quantitative information is often sparse or unavailable. If these weights are not specified correctly then the outcomes of the FCM may appear unrealistic (Eden and Ackermann, 2005). As relationships are only semi-quantified, interpretation in absolute terms is obstructed and the output from an FCM (after several iterations) cannot be directly translated into time (Kok, 2009).

6. Evaluation

Recent research on participation has shifted in focus from reporting on the benefits of participation, to designing processes which are effective and legitimate, often with a strong emphasis on evaluation. Traditionally evaluation criteria have been limited to process rather than outcomes, and while a useful set of practical recommendations and 'lessons learned' are emerging, a rigorous evaluation of the ability of participatory modelling to deliver its postulated benefits is required in order to compare and contrast the relative merits of different techniques (Rowe and Frewer, 2000; Abelson *et al.* 2003).

Evaluation that focusses solely on process is insufficient in flood risk management, where the outcomes of participatory processes (from a substantive and instrumental perspective) may be those most valuable to practitioners. It is argued that four key evaluation elements of a participatory process can be identified. Figure 11, developed after Webler and Tuler (2002) show how these four elements interact to form a cycle of evaluation.

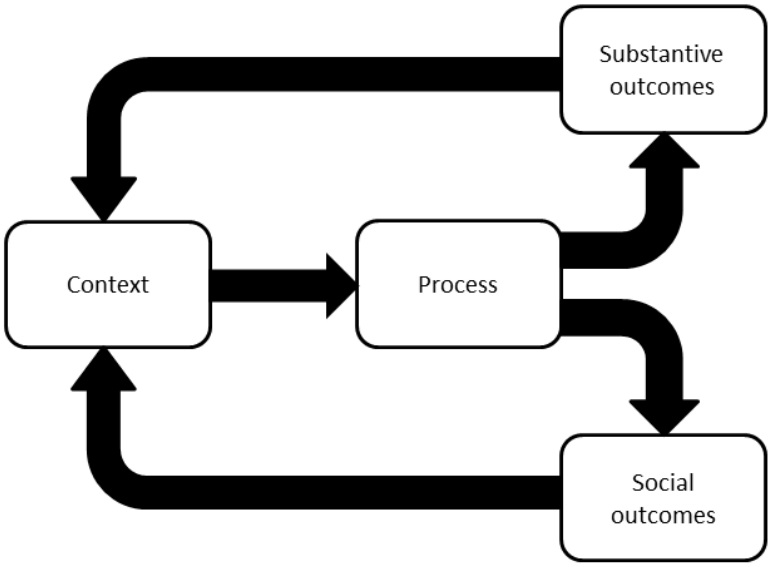


Figure 11: Evaluation elements

The first element, *context*, refers to the contextual factors and initial variables that shape the participatory process, and which can be altered during the process itself. The second, *process,* is essential for ongoing improvement of participatory processes and providing feedback to facilitators. The aim is to maximise the characteristics common to participatory processes (e.g. responsiveness) that support the production of useful outcomes. The third, *substantive outcomes*, assess a process against its ability to achieve user objectives and expectations, which are monitored throughout the process. Finally, *social outcomes* refer the ability of a process to enhance community flood resilience, and build the social capacities that enable a community to better prepare for, resist the impact of, respond to, and recover from, a flood event. Developing criteria for the evaluation of all four elements of participation, with a particular focus on its application in flood risk management, should be a priority for future research.

7. Conclusions

Assessing flood risk and applying the most appropriate management response is crucial if solutions are to achieve technical credibility, political understanding, and widespread public support (Harman *et al.* 2002). In the contemporary definition of flood risk, both likelihood and consequences contribute equally, but this is not the case in the way flood risk is currently modelled. Traditional numerical modelling often excludes local stakeholders, whose situated and experiential knowledge of previous flooding events and their social impact is critical to understanding flood consequences.

Limited guidance exists to support practitioners in understanding what they should seek from participation, what techniques are available to them, and what each might be expected to deliver in different contexts. This results in participation that is often limited to consultation, largely ineffective, and potentially damaging. Yet as responsibilities become shared out at the local level, organisations and individuals expected to manage flood risk increasingly lack the technical expertise required to access traditional models of flood likelihood. This paper outlines a flexible participatory approach (Figure 3) into which different participatory modelling techniques can be embedded. The important role of stakeholder analysis is emphasised, culminating in the development of a bespoke stakeholder analysis typology that can support the identification and prioritisation of participants. By reviewing the benefits of participation reported in the environmental management literature, this paper identifies five requirements of participation from a flood risk management perspective. It concludes that active participation of local stakeholders should be accessible, transparent, adaptable, evaluative and holistic: five qualities that provide the basis for a review of three popular participatory modelling techniques.

Techniques are required that are both accessible to local stakeholders with limited or no technical expertise, yet capable of modelling the complexity inherent in flood risk systems, in which receptors at risk are closely coupled to the pathways that connect them to the hazard. This paper argues that participatory modelling techniques, that guide participants through the process of co-producing conceptual models of cause and effect, are those best suited to capture and evaluate this complexity, yet remain sufficiently accessible and transparent. These techniques have the potential to structure participants' knowledge of how a system behaves, and how individual elements are causally related. While often not sufficiently robust to make predictions, they can be used to highlight community priorities, allay misconceptions, develop relationships, and build consensus.

This review reveals that different techniques place different emphasis on the five qualities, implying that practitioners will need to carefully consider which of the requirements they are seeking to maximise before making a choice about which technique to employ. It further identifies key limitations of each technique, which may preclude their application in certain contexts. It should be noted that many other techniques exist, that were beyond the scope of this paper to review. Further research, applying these and other participatory modelling techniques in the field of flood risk, will add to our understanding of what each technique can deliver, and in which contexts its use is most appropriate. If these applications are accompanied by thorough evaluation, the framework outlined in this paper can be iteratively developed and refined such that it offers flood risk practitioners a systematic way of reviewing whether or not participatory processes have been effective.

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II) Paper II.

Participatory modelling for stakeholder involvement in the development of flood risk management intervention options

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Abstract

Advancing stakeholder participation beyond consultation offers a range of benefits for local flood risk management, particularly as responsibilities are increasingly devolved to local levels. This paper details the design and implementation of a participatory approach to identify intervention options for managing local flood risk. Within this approach, Bayesian networks were used to generate a conceptual model of the local flood risk system, with a particular focus on how different interventions might achieve each of nine participant objectives. The model was co-produced by flood risk experts and local stakeholders. The study employs a novel evaluative framework, examining both the process and its outcomes (short-term substantive and longer-term social benefits). It concludes that participatory modelling techniques can facilitate the identification of intervention options by a wide range of stakeholders, and prioritise a subset for further investigation. They can help support a broader move towards active stakeholder participation in local flood risk management.

Highlights

- Case study uses participatory modelling approach to involve local stakeholders
- Application of Bayesian networks to co-produce a conceptual model of flood risk
- Testing of model with stakeholders to identify recommended interventions
- Approach evaluated using five requirements specific to flood risk management
- Approach effective at identifying interventions that merit further exploration

Keywords

Participatory modelling, Bayesian networks, flood risk, stakeholder, evaluation, social capacity

Software availability

Netica (CoGF) 4.16 for Windows ©1992-2015. Norsys Software Corporation, 3512 West 23rd Avenue, Vancouver, BC, CANADA, V6S 1K5. Available online from http://www.norsys.com/netica Cost US$285.00(academic) / US$585.00(commercial) (both include technical support and updates for one year). Free demo version available for download at above website (full-featured but limited model size supported).

1. Introduction

The identification of intervention options is a key component of a local flood risk management (FRM) decision-making process. Considerable national and/or regional variation exists in how it is conducted (*cf.* EA, 2010), but at a high-level it can be summarised into six, generic steps (Figure 1): a) problem definition; b) objective setting; c) benchmark development and setting; d) intervention option scoping and identification; e) intervention option appraisal and; f) intervention option recommendation / selection.

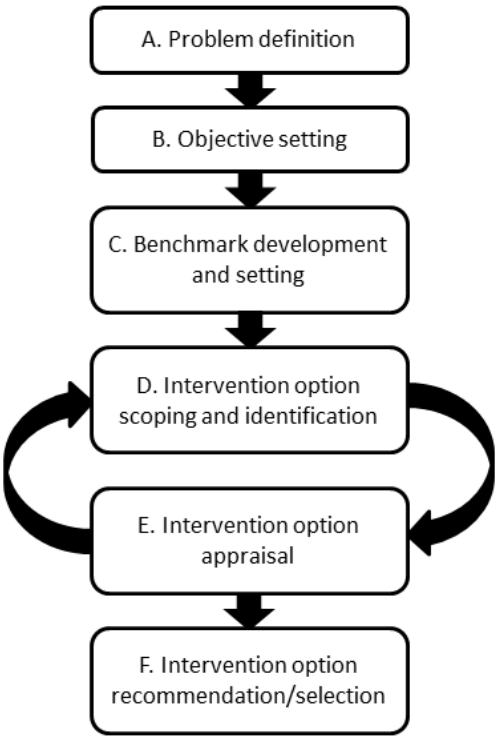


Figure 1: Generic steps in flood risk decision-making

Feedback and iteration is usually employed to help inform and refine options appraisal (steps d-e). However, options identification (steps a-d) is structured more sequentially (although a planning cycle in which objectives and benchmarks are reviewed is commonly included). The sequential structuring of options identification steps means the framing of a local flood risk problem is particularly critical because it constrains the set of FRM objectives that drive the remainder of the process. Incomplete or inaccurate framing may produce poorly formulated objectives which, in turn, may result in incomplete or inappropriate identification of options for appraisal. Thus, the specific local contexts (both physical and socio-economic) that frame a local flood risk problem must be fully understood and explicitly represented within local FRM decision-making processes (Johnston and Soulsby, 2006; Prell *et al.* 2007). There is, therefore, a strong imperative for FRM practitioners to include the elicitation and integration

of situated, stakeholder knowledge (Wynne, 1996; Evans and Plows, 2007) within the options identification steps of local FRM decision-making (RELU, 2010; Haughton *et al.* 2015).

In response, formal planning for stakeholder engagement has become a requirement in many FRM options identification and appraisal policies (e.g. USACE, 2000; 2005; EA, 2005; 2006; 2010; DEFRA, 2011; CIS, 2012) and stakeholders are increasingly seen as full partners rather than consultees in FRM decision-making process (White *et al.*, 2010). However, guidance for practitioners on how stakeholder knowledge can and should be integrated into local FRM options identification, and the benefits that it can deliver, is underdeveloped. Considerable uncertainty about the methods and tools that can be used to engage local stakeholders exists, resulting in wide variation in the nature and scale of engagement across different local FRM projects (e.g. AECOM, 2012; NCC, 2013). The objective of this paper is to improve the guidance that is available by exemplifying how a participatory modelling approach (*cf.* Greenland and Brumback, 2002; Voinov and Bousquet, 2010), coupled with a simple Bayesian network model (BNM), can help to support enhanced options identification in local FRM contexts.

The approach taken is particularly novel in the context of FRM in the respect that it presents a model, co-produced with local participants, that views FRM through the wider lens of integrated catchment management, evaluates the potential impacts of a range of interventions (both singular and cumulative), and takes into account both the physical and social systems in which these interventions will ultimately operate. In this respect it represents a considerable departure from previous attempts at participatory flood risk modelling (e.g. Lane *et al.*, 2011) where models have focussed on participants' understanding of one aspect of the system (e.g. flood hydrology), and their ability to contribute to developing a single intervention based on a limited knowledge of that aspect. By taking a more holistic view of FRM, this approach both acknowledges and utilises a wider stakeholder knowledge base than previous studies.

The remainder of the paper is structured as follows. Section 2 briefly outlines the principle arguments for and against the adoption of stakeholder participation and participatory modelling in local FRM decision-making. In Section 3 we present a case study in which participatory modelling is used to support a local FRM options identification process. We outline the principles and goals of the approach along with the three-stage structure by which it was organised. The methodology is presented in Sections 4 and 5. Details of the stakeholder analysis methodology employed to identify participants, and to inform the local FRM objectives, are provided in Section 4. The participatory modelling methodology (including the approach, tools used and the co-production process) is described in Section 5. In Section 6 we present the local FRM intervention options identified by the participatory model.

Section 7 provides a comprehensive evaluation of the participatory modelling process and its outcomes. Finally, lessons for using participatory modelling in local FRM are synthesised in Section 8.

2. Stakeholder participation in flood risk decision-making

The participation of stakeholders throughout environmental decision-making (including FRM) is an established principle, underpinned by a comprehensive statutory framework (e.g. ICWE, 1992; UNEP, 1992; UNECE, 1998; EC, 2000; 2003; 2007). Expert knowledge *per se* is increasingly seen as insufficient for informing decisions concerned with specific local contexts (e.g. Wynne, 1992; 1993, Robbins, 2000; Cinderby and Forrester, 2005; Eden *et al.*, 2006; Douglas *et al.*, 2010). Instead, it is recognised that in many decision-making processes the adoption of a participatory paradigm (Brown and Damery, 2002; Reed, 2008; Barreteau *et al.*, 2010) is needed so that those possessing both certified expertise and situated knowledge (which need not be mutually exclusive) can be effectively engaged in the co-production of the knowledge necessary to inform decisions (Callon, 1999).

Three benefits of a participatory paradigm are regularly cited (see Fiorino, 1990; Stirling, 2006; Chilvers, 2008a,b; 2010): 1) normative benefits that enhance citizen empowerment, equity and social justice in decisions and the evidence that underpins them (e.g. Renn *et al.*, 1995; Bohmann, 1996); 2) instrumental benefits that enhance the legitimacy of evidence and decisions, and the trust that is afforded to them (e.g. Gaddis *et al.*, 2010; Voinov and Bosquet, 2010) and; 3) substantive benefits that enhance the quality of the evidence underpinning the decisions that are ultimately made (e.g. Stirling, 1998). In FRM, the findings from several recent participatory studies appear to confirm this by reporting a range of normative and instrumental benefits (Landstrom *et al.*, 2011, Lane *et al.*, 2011; Odoni and Lane, 2010; Ryedale Flood Research Group, 2008; Whatmore, 2013).However, the notion that participatory approaches and the engagement of stakeholders alongside certified experts will inevitably lead to better decision-making should be avoided. The value of stakeholder 'expertise' remains contested within social science generally (e.g. Jasanoff, 2003; Collins and Evans, 2008; Tsouvalis and Waterton, 2012) and FRM practice in particular (e.g. Haughton *et al.*, 2015). Previous studies highlight important challenges related to the biases of those participating in the decision-making process, and the effectiveness of the approaches and tools used to facilitate the participation and represent the knowledge that is co-produced (*cf.* Irwin, 1995; Wynne, 1992; 1993). In FRM, Haughton *et al.* (2015) caution against a 'romanticised view' that local stakeholders are always necessary and beneficial for the creation and stewardship of situated flood risk knowledge. Instead, the case for participation should be supported by comprehensive evaluation of the extent to which participatory approaches deliver beneficial outcomes for local FRM decision-making processes. In this regard, the limited number of

published studies providing such evaluation is a significant constraint on the guidance that is available to FRM practitioners, and is something that this study helps to redress.

3. The participatory modelling case study

The remainder of this paper focusses on the development of a participatory local flood risk intervention model for Hebden Bridge and its evaluation. Hebden Bridge is a small market town (population 4,500) situated roughly eight miles west of Halifax, West Yorkshire, UK (Figure 2). The town centre is located on a narrow floodplain located at the confluence of the River Calder (catchment size 957km^2, mean discharge ~4.1 m^3 s^{-1}) and Hebden Water (catchment size 59km^2, long-term mean discharge ~0.7 m^3 s^{-1}), surrounded by a steep sided valley (Figures 2 and 3). Both the River Calder and Hebden Water drain large upland catchments where high-intensity, convective rainfall events occur. The catchment physiography results in a flashy hydrological regime; and if high discharge in Hebden Water and the River Calder coincide, flow in Hebden Water backs up, flooding the town centre. In addition, localised, convective rainfall contributes to incidences of pluvial flooding. In summer 2012 Hebden Bridge experienced two major instances of flooding; the first being primarily fluvial and the second pluvial. On the 22nd June, discharge in the River Calder peaked at 190 m^3 s^{-1} (~ 1:70 year flood) resulting in a back-up of water into Hebden Bridge town centre, which peaked at 1.97 m stage (Figure 3) and flooded 219 properties (CMBC, 2013a). A second event on 9th July was a result of intense localised rainfall from a short-lived storm cell, and flooded around 100 properties including several affected by the June event (CMBC, 2013b).

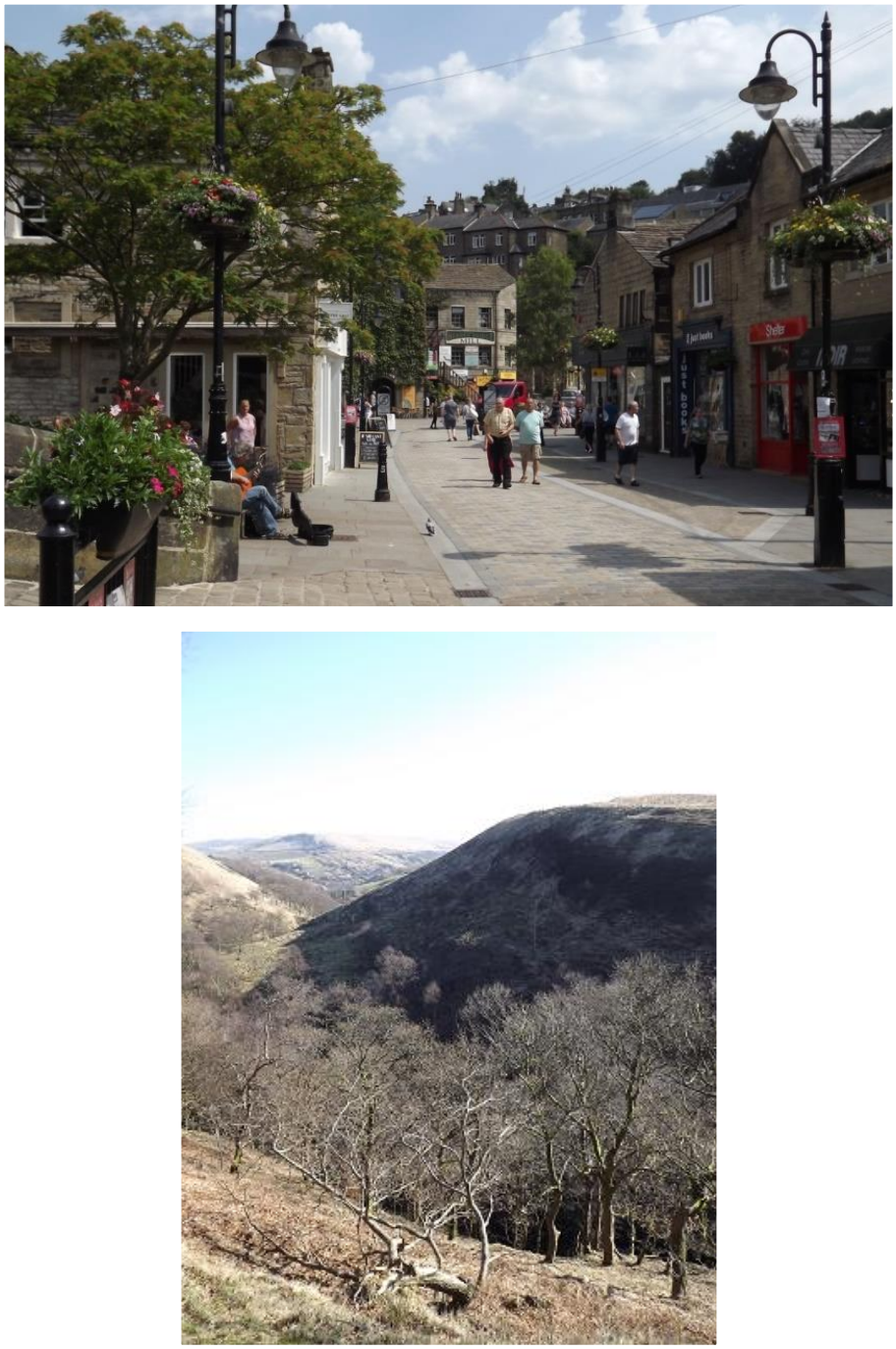


Figure 2: Hebden Bridge town centre (top) and surrounding landscape (below)

Despite these events, and further flooding in 2015, Hebden Bridge remains largely undefended. Topographical constraints and the challenges of trying to combat both fluvial and pluvial flooding mean that is has been difficult to identify appropriate and affordable flood interventions for the town. The high capital cost of hard-engineered schemes and the need to raise funding through local partnerships (*cf.* Thaler and Priest, 2014) have been significant barriers. Moreover, controversy exists around hard-engineered interventions over concerns that they could endanger the town's attractive and historic urban setting (Figure 2) which underpins much of its local economy. Following the 2012 floods, it was

recognised that the reduction of flood risk in Hebden Bridge may need to be affected through interventions designed to enhance the town's flood resilience, rather than to reduce the likelihood/magnitude of flood levels. This prompted a collaborative project between the Environment Agency for England and Wales, Calderdale Metropolitan Borough Council (the Lead Local Flood Authority) and researchers at the University of Nottingham.

The project aimed to design and test a new approach to FRM options identification that structured, formalised and integrated the situated knowledge of local stakeholders and expert knowledge of practitioners (hereafter termed 'participants') in a process of co-production. The objective was to develop a participatory model of local flood risk interventions from which novel options, perceived to be suited to the specific local physiographic and socio-economic context of Hebden Bridge, could be identified. These could then be advanced for formal appraisal. In addition, the project also sought to deliver an evaluation of the extent to which the process of developing a participatory flood risk intervention model could deliver normative and instrumental benefits required to promote social learning amongst the participants.

Three principles governed the project:

Principle 1 The participatory model must be the combined product of the knowledge of those who participated in its construction;

Principle 2 The transparency and accessibility of the modelling methods used must be sufficient to enable *all* participants (including those with low levels of numerical and/or technical skill) to be fully engaged in the model development process and to be capable of continuing to use the resultant model;

Principle 3 The participatory modelling process should maximise the quality, rather than the volume, of participatory elements in order to maintain the engagement of the participants (the majority of whom were volunteers giving up their free time).

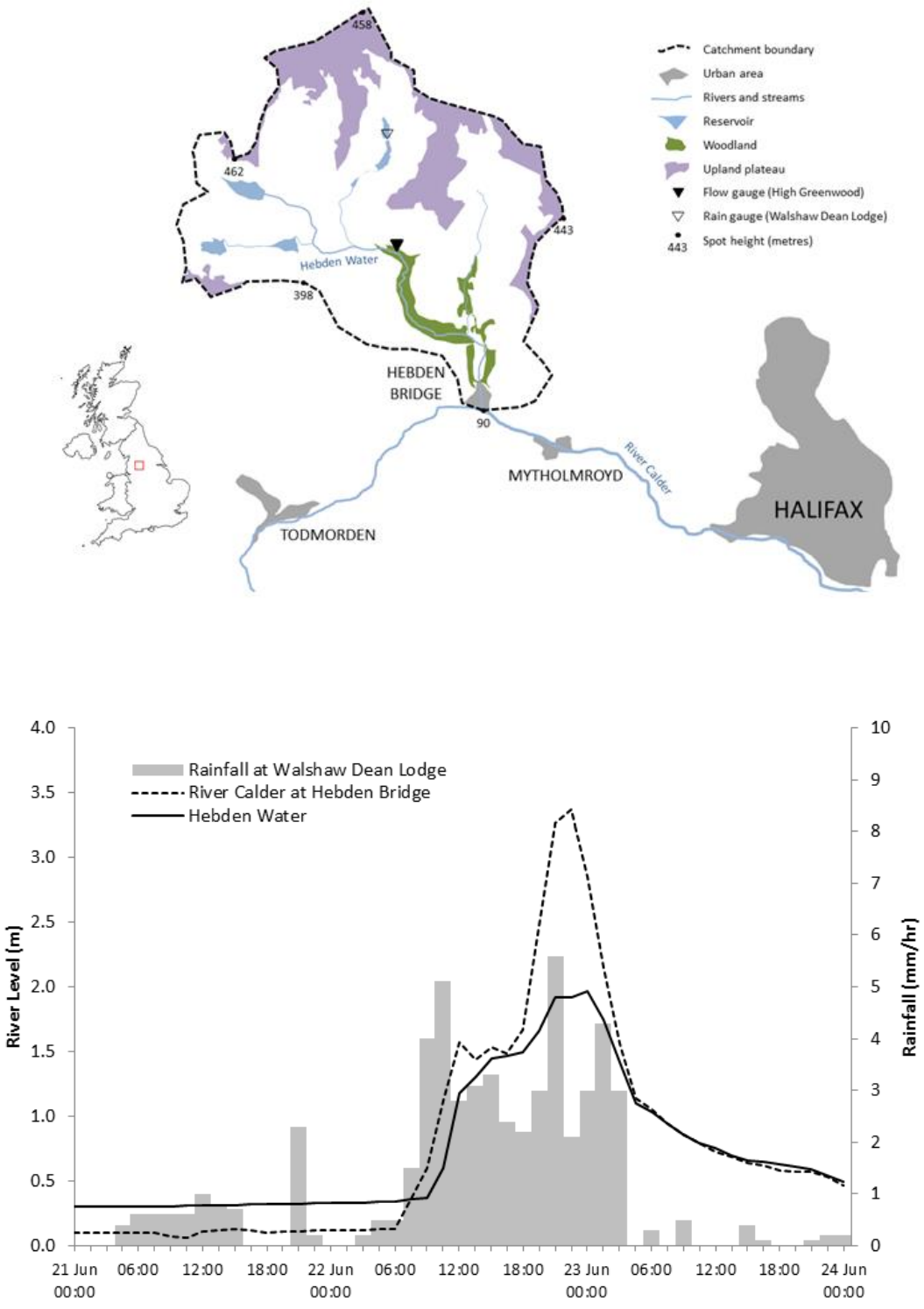


Figure 3: Hebden Water catchment with inset UK locator map (above) and hydrograph from 21-24 June 2012 (below). Redrawn from the Upper Calder Flood Hydrology Report (EA, 2012)

The participatory modelling process had three goals:

1. To establish a set of local flood risk management objectives that interventions should address (i.e. step b in the options identification and appraisal process);
2. To produce a formal model of the participants' perceptions and understanding of local flood risk cause and effect and the impact that alternative interventions might have on these;
3. To explore the relative extent to which alternative intervention options might be able to address the objectives, and to inform a shortlisting of interventions that the participants identified as warranting further appraisal (i.e. step d in the options identification and appraisal process).

In order to achieve these goals, the participatory modelling process was structured into three key stages (Figure 4):

Stage 1 — A coupled stakeholder-led determination of a set of objectives for reducing flood risk in Hebden Bridge and analysis of stakeholders with the situated knowledge necessary to inform the modelling process (see Section 4);

Stage 2 — The co-production of a BNM of local flood risk interventions representing participants' shared understanding of the local flood risk system and the interactions between interventions and objectives within the system (see Section 5);

Stage 3 — The application of the model to explore and assess the impact that applying different interventions (and combinations thereof) had on the objectives (see Section 6).

Importantly, it was recognised from the outset that the scope of the interventions considered should not be constrained to physical components of the flood risk system (i.e. management of flood sources and pathways), but should include aspects by which the impact on receptors might be managed (e.g. social actions and blue-green infrastructure). It is also important to note that neither the participatory modelling process, nor the model it produced, were conceived as a replacement for the hydraulic, hydrologic, economic and social models that would be needed to inform comprehensive options appraisal (*cf.* Evans *et al.* 2002; Sayers and Meadowcroft, 2005).

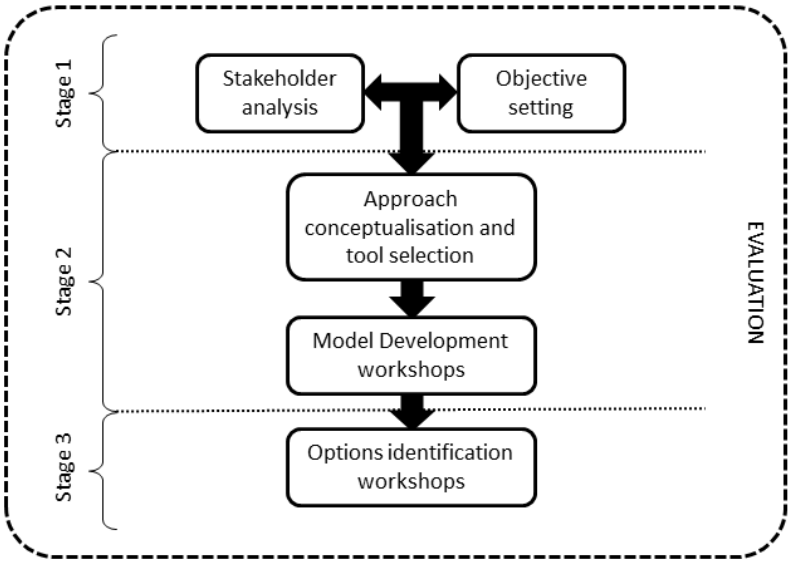


Figure 4: The structure of the participatory modelling process used in Hebden Bridge

4. Stakeholder analysis and objective setting (Stage 1)

The outcomes of a participatory modelling process will inevitably reflect the knowledge and understanding of the participants. A systematic method for analysing stakeholders, and identifying those with the breadth and diversity of situated knowledge required to meet the goals of the participatory process, is essential (Mitchell *et al.* 1997; Bryson, 2004; Reed *et al.* 2009). In this project, there was a lack of pre-existing relationships with stakeholder groups (e.g. local flood action group or residents / business owner campaign groups). This made it necessary for the researchers to identify and traverse local networks of stakeholders, so that the FRM objectives for Hebden Bridge could be elicited and project participants could be identified. To this end, an iterative, top-down stakeholder identification methodology was used (Dougill *et al.* 2006; Prell *et al.* 2008), which is sometimes referred to as 'snowballing' or 'referral sampling' (Harrison and Qureshi, 2000; Hair *et al.*, 2010). To minimise sampling bias and the marginalisation of stakeholder groups (Ananda and Herath, 2003; Reed, 2009), a simple stakeholder classification of key players, context setters, subjects and the crowd (*cf.* Eden and Ackermann, 1998; De Lopez, 2001) was adopted. This enabled the project team to structure the range of stakeholders that were identified according to the diversity of their local flood risk interest, expertise and experience (Figure 5). Stakeholders that mapped to the quadrants overlapping the high-interest, high-influence regions of the classification were invited to participate in the project as an initiation group.

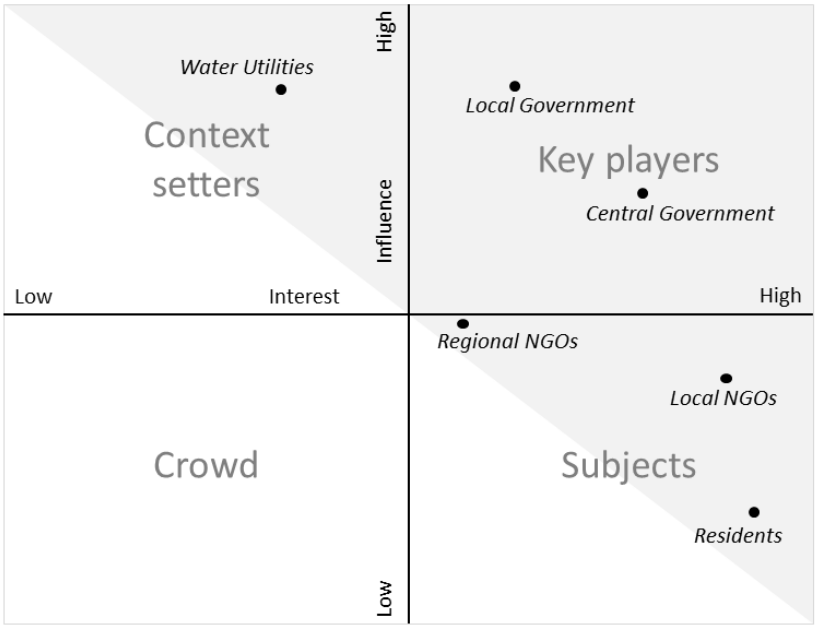


Figure 5: Stakeholder mapping (after Eden and Ackermann, 1998; De Lopez, 2001)

The initiation group was interviewed, with the transcripts (n=10) analysed in order to extract two key sets of information: i) a set of FRM objectives for Hebden Bridge (Table 1); and ii) any other stakeholders that should be referred. Utilising a referral-based stakeholder analysis was successful in maximising the efficiency of stakeholder identification. It resulted in a final participant group comprising 40 stakeholders representing 14 separate organisations / groups (Table 2). They represented a wide range of situated knowledge and expertise (*cf.* Collins and Evans, 2008) including certified experts from context setting and key player organisations and uncertified experts from local community and campaigning groups.

Table 1: Catchment objectives

Objective	Description
1	To reduce surface runoff
2	To store and slowly release excess stormwater from appropriate areas
3	To create more space for water in the river
4	To improve land management
5	To manage the flow of surface water
6	To adopt water-sensitive approaches to construction and development, which offer multiple benefits beyond those of reducing flood risk
7	To understand the current role of the reservoirs
8	To raise awareness of what residents can do to prepare for flooding
9	To raise awareness of what residents can do to recover from flooding

Table 2: Participating stakeholder organisations/groups

Organisation/group	Description	Participants
Environment Agency	National regulator	3
Calderdale Metropolitan Borough Council	Local government and lead local flood authority	11
Yorkshire Water	Water utility	1
National Trust	Landowner	1
Hebden Bridge Partnership	Local non-governmental organisation (NGO) (community, recreation and tourism)	2
Business Owners Association	Local NGO (business, trade and tourism)	2
Calder and Colne Rivers Trust	Local NGO (recreational and ecological stewardship)	2
Treesponsibility	Local NGO (land management)	3
Pennine Prospects	Regional NGO (upland management)	1
Moors for the Future	Regional NGO (upland management)	2
National Flood Forum	National NGO (support for communities at flood risk)	1
University of Leeds	Research institution	2
University of Nottingham	Research institution and facilitator	4
Local residents	No affiliation	5

5. Participatory model development: Conceptualisation, approach, tools and activities (Stage 2)

5.1 Conceptualisation of the local flood risk system

A major challenge for any participatory modelling project in which the goal is for participants to co-produce the model is the selection of the modelling approach and tool. To maximise their legitimacy they should offer all participants equality of access and use. However, this can be difficult where the diversity of the participants is high and includes those with high levels of technical and numerical expertise and those with little. This was the case in Hebden Bridge where some participants had substantial expertise in flood risk modelling (e.g. participants from the Environment Agency) whilst others had none and little confidence in quantitative modelling methods. Therefore, a highly conceptual modelling methodology was devised that abstracted the local flood risk system to set of cause-effect relationships between flood risk objectives, controlling factors, potential interventions, implementation factors and intermediate factor variables (Table 3). This conceptualisation paralleled the vernacular used by many local stakeholders to express their understanding of the flood risk system. This meant that the model variables could be elicited directly from participants through directed, group discussion with no assumed level of technical competence. It also facilitated structure the structuring of knowledge using simple probabilistic representations, formalised within a simple Bayesian network model (BNM) that offered both quantitative rigour and ease of understanding for all participants (see Section 5.2).

Table 3: Variables in a cause-effect model of local flood risk intervention

Variable Type	Definition	Example
Objective	A variable describing an **outcome** that may be affected by interventions within the physical / socio-economic systems.	Flood probability, property level resilience, community awareness, response planning.
Intervention	A variable encoding an **action** that could be taken to help achieve an objective.	Property-level protection, drain maintenance, education programme, flood warden scheme.
Implementation Factor	A variable whose state determines whether an intervention can be successfully **implemented**.	Funding, the planning system, land availability, environmental protection, visual impact.

Control Factor	A variable that exerts **control** over the flood risk system that cannot be easily manipulated or modified.	Precipitation intensity, topography, storm water system, pre-existing flood plain development.
Intermediate Factor	A variable between an intervention and objective needed to **explain** the cause-effect.	Channel capacity, infiltration rate, demographic composition.

5.2 Participatory modelling approach and modelling tool

Co-production of the model was structured around four model building tasks:

Task 1 Identification of the variables that must be represented in the participatory model;

Task 2 Structuring of the causal pathways between them;

Task 3 Formalisation of each variable as a state variable – i.e. that can hold a mathematical description of its state at any given time;

Task 4 Formalisation of the mathematical, cause / effect relations that are transmitted along the causal pathways and influence the states of each variable.

In participatory modelling, formalised approaches (Voinov and Bousquet, 2010) direct the eliciting and structuring of participants' knowledge (Tasks 1 and 2). Whilst a number of different participatory modelling approaches have been proposed (e.g. Vennix, 1996; Barrateau, 2003; Palmer *et al.*, 2013), this project employed an adaptation of the mediated modelling approach of Van den Belt, (2004) (Figure 6). Mediated modelling was considered particularly appropriate for Hebden Bridge because it gives salience to the process of interfacing participants with different levels of expertise so that models can be co-produced that are readily understood and accepted by all participants.

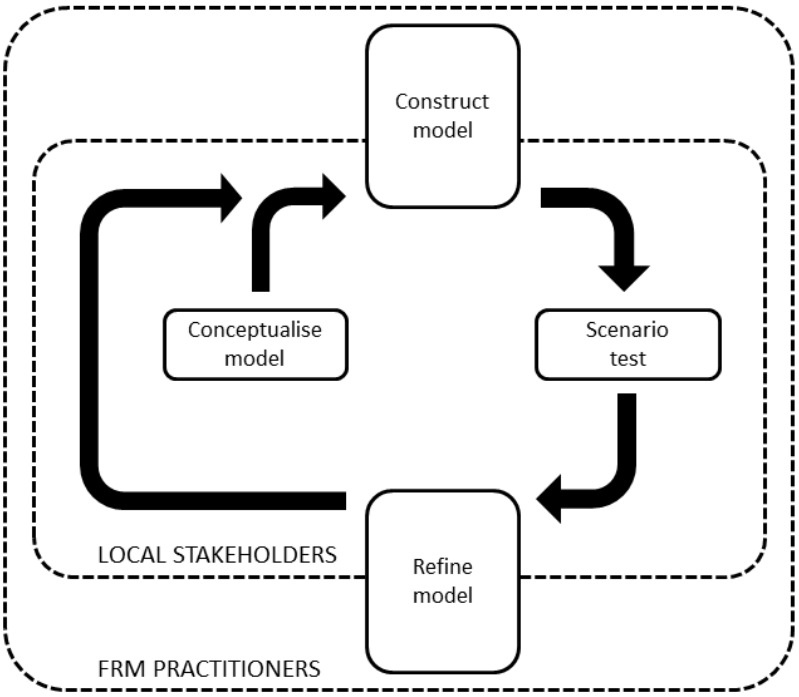


Figure 6: Mediated modelling approach (after Van den Belt, 2004)

To complete Tasks 3 and 4, quantitative or semi-quantitative tools are needed to provide a mathematical formalisation of model variables (Table 3) and the propagation of cause and effect between them. In Hebden Bridge it was decided to use a BNM (Pearl, 1985; 1988; Varis, 1995) due to the relatively simple and intuitive way in which it supports conceptual modelling of environmental systems, and due to the flexibility with which different knowledge types can be represented within it (for a review see Aguilera *et al.* 2011).

A BNM combines Bayesian probability theory and notions of conditional independence. It is a directed acyclic graph (Greenland and Brumback, 2002) whose edges are the causal or inferential links between uncertain variables that have a number of discrete states (Neil *et al.*, 2000). Conditional probability tables (CPTs) associated with each variable represent the uncertain relationship between the states of each variable and its parents (Hanneman, 1988). Examples of the use of BNMs to model environmental systems are numerous (e.g. the management of fisheries (Kuikka *et al.* 1999; Borsuk *et al.* 2001; Little *et al.* 2004), catchment management (Ames *et al.* 2005) and water resource use (Varis and Kuikka 1997; Batchelor and Cain, 1999)), and they have been shown to be an effective tool for engaging stakeholders so that gaps in evidence bases can be addressed (Varis and Kuikka, 1997; Henriksen *et al.* 2007). Studies highlight several benefits of BNMs including the ability to structure and combine knowledge from multiple sources (Marcot *et al.* 2001; Ticehurst *et al.* 2007), represent a system conceptually without requiring the explicit representation of all system processes (Borsuk *et al.* 2004), and easily update a

model as new data or knowledge becomes available (Castelletti and Soncini-Sessa, 2006; Ticehurst *et al.* 2007).

In the majority of examples of BNMs reported in the literature (e.g. Smith *et al.*, 2007; Murray and Klinken, 2012; Smith *et al.*, 2012; Murray *et al.*, 2014), the objective of the Bayesian network model is the delivery of substantive outcomes. Most commonly, this centres on providing enhanced prediction through a model development process that is informed by experts possessing moderate levels of technical and numerical expertise. However, in this study broader outcomes from the modelling process were sought, including the delivery of normative and instrumental benefits alongside substantive ones. To this end, studies that have shown BNMs to be capable of facilitating participation-led studies are of particular relevance (*cf.* Marcot *et al.* 2001; Castelletti and Soncini-Sessa, 2006; Henriksen *et al.* 2007; Lynam *et al.* 2007; 2010; Zorrilla *et al.*, 2010).

Importantly, structuring a BNM can be achieved graphically, without the need for any specialist software. The structure can then be populated with knowledge elicited directly from participants in the form of probability values. This simplicity means BNMs are ideally placed for use in participatory settings; especially where each participant's knowledge of the probability of relevant causes and effects may be highly developed, but their numerical skills to formalise these as a model may be limited (Castelletti and Soncini-Sessa, 2006). Moreover, BNMs support the bi-directional computation of conditional probabilities along the causal links between parent and child variables (i.e. how will a change in the likelihood of states in parent variable *A* affect the likelihood of states in child variable *B* and vice versa) (*cf.* Ames *et al.* 2005; Castelletti and Soncini-Sessa, 2006; Aguilera *et al.* 2011). This means that a BNM can be used to infer the adjustments needed throughout a system in order to maximise the likelihood of one or more specific objectives (i.e. a desired set of variable states) (Ames *et al.*, 2005; Sendzimir *et al.* 2007). Just such a capability is an essential requirement for local FRM options identification, where the objective of the exercise is to identify which interventions, if implemented, offer the greatest likelihood of delivering the local flood risk objectives.

5.3 Model development and calibration

The co-production of the BNM was conducted between June 2013 and March 2014 through activities designed around a sequence of five model development workshops (Figure 7). The recent nature of the flooding events in Hebden Bridge was beneficial to the extent that it enhanced the level of participant engagement in the workshops. However, it also introduced the likelihood that participants' perceptions would be biased by their specific experiences during the recent floods. To some extent this was diluted through the diversity of the participants, many of whom (e.g. local government representatives,

landowners, etc.) had no first-hand experience of the flooding and were not at significant risk. Nonetheless, the inclusion of participants whose perceptions were influenced by their experience of recent events was considered wholly appropriate, given that the purpose of the exercise was to identify local flood risk interventions options following an acute event.

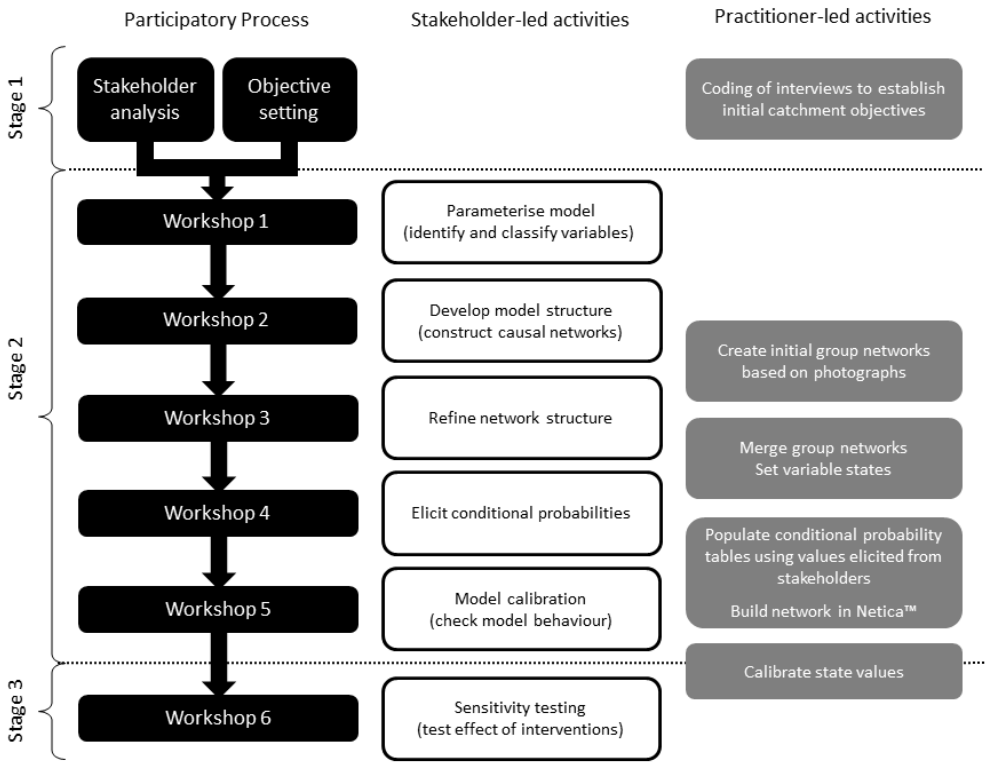


Figure7: Participatory approach adopted in Hebden Bridge

In workshop 1 the participants worked in small groups (n = 5) to parameterise the model. Working backwards from each flood risk objective, participants identified as many interventions as possible that they thought might contribute to achieving it. Participants were reminded that the intervention options could include actions to reduce the exposure and/or vulnerability of flood receptors as well as those that might disrupt flood sources and pathways. For each intervention, they then identified factors that might determine whether or not it could be implemented, factors that could control its performance if implemented and any intermediate factors needed to explain the causality chain between the objectives, interventions, implementation and control factors. A total of 82 variables were identified, including 18 potential interventions spanning surface water and channel management, upland catchment management, social behaviours and the adoption of blue-green infrastructure.

In workshops 2 and 3 the participants co-produced a model structure. All of the variables from workshop 1 were transferred to coloured cards (coded according to the variable types in Table 3). In two groups, participants were asked to work backwards from the objectives; arranging and linking the

variables together with edges that represented perceived cause-effect dependencies. The structures defined by the participants incorporated both definitional / synthesis and cause-consequence idioms (Neil *et al.*, 2000). This resulted in two 'networks of causality' that documented participants' situated knowledge of intervention options that might help to achieve the flood risk objectives for Hebden Bridge, and the dependencies that could determine their success (Figure 8). Each network was photographed. These networks were then iterated and refined in workshop 3 with the participant groups working through each variable, confirming the parent variables that could affect its state, removing erroneous relationships and/or adding any additional ones where they were felt to be missing.



Figure 8: An example 'network of causality' produced by the participants during workshop 2

Between workshops 3 and 4, the University of Nottingham researchers and staff from the Environment Agency concatenated the participants' networks into a combined version (Figure 9); removing duplicate cause-effect structures and streamlining where necessary to remove intermediate variables. The final network was organised according to the different sectors of the flood risk system represented within the variable set (e.g. channel, upland catchment, surface water (drainage and storage), social and blue-green infrastructure). Of particular importance to this process are recent arguments which assert that the use of traditional 'risk = likelihood x impact' structures are invalid in the case of Bayesian networks (Fenton and Neil, 2013). The participants' initial structuring of flood risk (which reflected the traditional structure) was adjusted so that it reflected a 'trigger, event, consequence, control and mitigant' structure which is advised for use in Bayesian network-based risk assessment.

All variables in the sectors were instantiated with discrete, qualitative binary states (e.g. High / Low; Desirable / Undesirable) as a pragmatic response to the constraints on model complexity imposed by Principles 2 and 3 of the participatory modelling process (Section 3). We recognise that more complex discrete variables are regularly used in BMNs to overcome the limited resolution that binary variables permit. However, established methods for modelling the large number of conditional probabilities that must be populated in the CPTs of ranked variables are best applied where participants have a moderate degree of statistical expertise (*cf*. Fenton *et al.* 2007: 7). Moreover, benchmarking experiments reveal that the time required to do this can extend to several days, even in a relatively small BNM (ibid: 9). Thus, the use of ranked variables was considered desirable but impractical in this project. Similarly, it could be argued that the simplification imposed by use of qualitative variables throughout prevented the inclusion of numeric formalisations (supported by dynamic discretisation (Neil *et al.*, 2007)) that could have been more appropriate for some variables (e.g. the 'cost of available insurance' variable was assigned states 'High' or 'Low' rather than real cost values). This decision was taken in order to maximise the ease with which tacit knowledge (which is an 'essential complement to explicit knowledge' (Gertler, 2003:78)) could be reflected in the model (Gacitua *et al.*, 2009), and to preserve its 'perceptions-driven' nature (see Principle 2, Section 3). Indeed, the construction of a perceptions-driven model was sought as a response to local FRM legislation in the UK which has increased the influence of stakeholder *perception* in FRM decision-making processes – even if it is not clear that the perception is supported by quantitative evidence (see Thaler and Priest (2014) for a recent exploration of the issues).

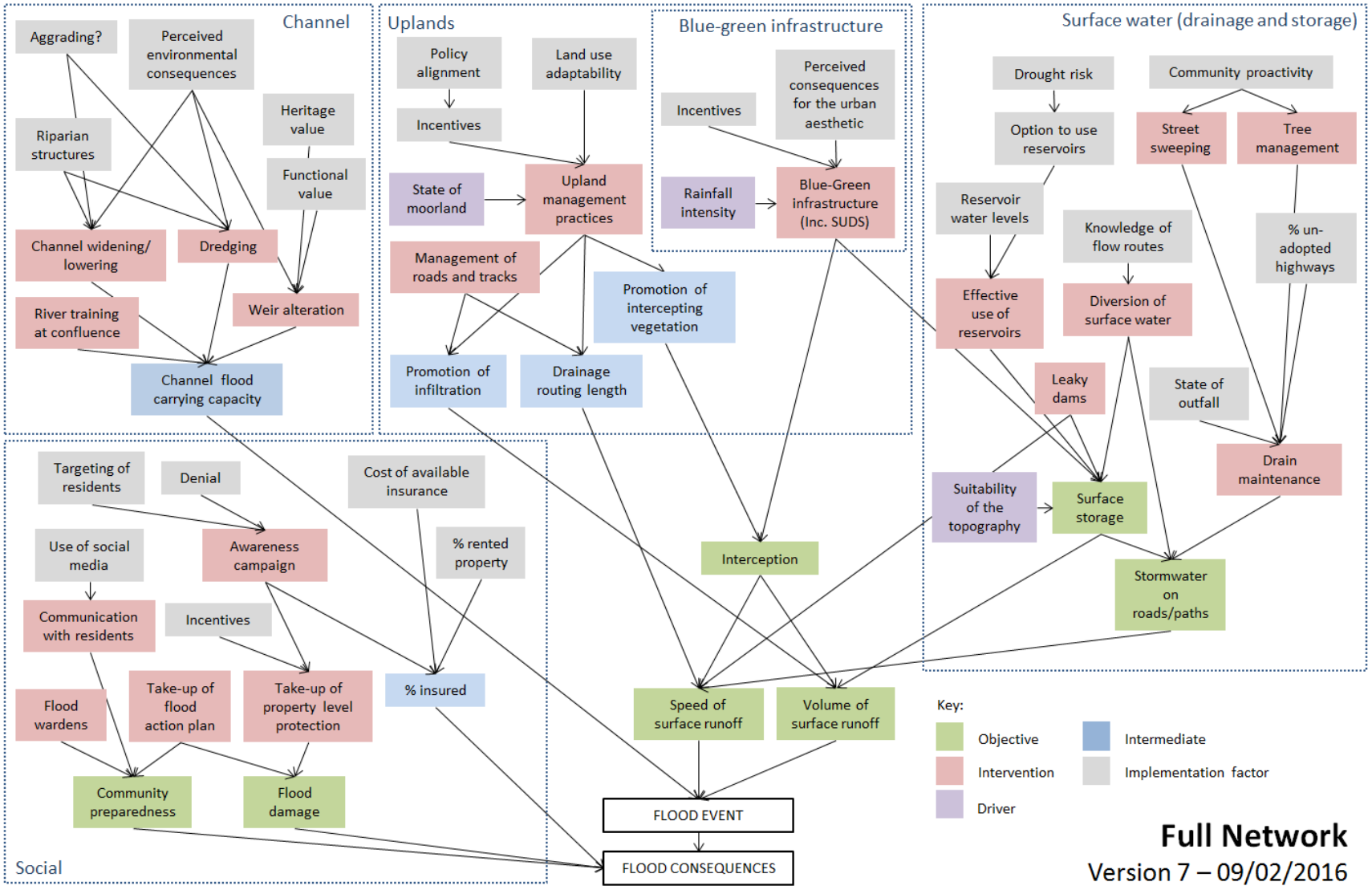


Figure 9: The final Bayesian network model structure showing the five model sectors

In Workshop 4 the conditional probability values needed to populate the model variables' CPT were directly elicited, with the remaining values being interpolated in order to enhance the efficiency and reliability of CPT population (Zagorecki and Druzdzel, 2004). The elicitation process was based upon group consensus, following the principles outlined in Renooij (2001). For all elicitation tasks, participants examined each model sector in small groups (n = <5) and the elicited values were an agreed representation of the group's collective view. In an effort to minimise motivational and / or cognitive bias (Skinner, 1999), the groups consisted of both expert practitioners and local stakeholders, and group membership was varied for each elicitation task. Elicitation was conducted one variable at a time, limiting focus to each individual child variable and its parents. Whilst multiple repetitions of the elicitation process for each variable would have further enhanced the robustness of the data (enabling formal testing for bias and uncertainty), achieving this in Hebden Bridge was impractical due to the relatively short time available to complete the participatory modelling process (6 workshops) and the size of the BNM that the participants produced (comprising 59 variables).

Cain's (2001) method for interpolating CPTs on the basis of a small number of elicited values was used to complete the CPTs of all child variables. By contrast, the prior probabilities contained in the CPTs of variables at the network margin (i.e. the implementation or control factors variables that determine the boundary conditions in which the flood risk system represented in the BNM operates) were fully elicited from the participants so that they reflected the perceived 'current conditions' in Hebden Bridge. Cain's method has similarities to the popular Noisy-OR gate approach (Diez, 1993; Huang and Henrion, 1996; Onisko *et al.*, 2001; Anand and Downs, 2008) which differs in the method interpolation and in its use of two elicited end member states (rather than one) to constrain the interpolated values. Like Noisy-OR, it ensures logical consistency in the elicited probabilities and reduces the number of probabilities that need to be elicited from stakeholders (Smith *et al.* 2007; Bashari *et al.* 2009, see also Bromley 2005; Chen and Pollino, 2012). The following worked example exemplifies the method and its key assumptions, with the results contrasted against a Noisy-OR interpolation of the same CPT.

A conditional probability table for a binary child variable (Z) with three binary parent variables (A, B, C) is presented in Table 4. All variables have states High (H) and Low (L). Conditional probabilities for the eight possible parent variable state combinations are required to populate the table. Five of these have been elicited. $P(Z_H|A_HB_HC_H)$ and $P(Z_H|A_LB_LC_L)$ are end members that determine the upper and lower limit of the conditional probability values in the table. The proportional difference between $P(Z_H|A_HB_HC_H)$ and $P(Z_H|A_HB_HC_L)$ reflects the independent impact of changing the state of parent variable C from High to Low. Similarly, the proportional difference between $P(Z_H|A_HB_HC_H)$ and $P(Z_H|A_HB_LC_H)$ reflects the independent impact of changing the state of parent variable B, whilst the proportional difference between $P(Z_H|A_HB_HC_H)$ and $P(Z_H|A_LB_HC_H)$ reflects the independent impact of changing the

state of parent variable A. These proportional differences become the interpolation factors that are used for estimating unknown values of $P(Z_H|ABC)$.

Table 4: Elicited and interpolated conditional probability values for a child variable with three binary parents using Cain's method and Noisy-OR. Elicited values are presented in regular font. Interpolated values are presented in bold italic font.

Parent Variable State			$P(Z_H\|ABC)$ Cain	$P(Z_L\|ABC)$ Cain	$P(Z_H\|ABC)$ Noisy-OR	$P(Z_L\|ABC)$ Noisy-OR
A	B	C				
H	H	H	0.95	0.05	0.95	0.05
H	H	L	0.9	0.1	0.9	0.1
H	L	H	0.7	0.3	0.7	0.3
H	***L***	***L***	***0.663***	***0.337***	***0.599***	***0.401***
L	H	H	0.3	0.7	0.3	0.7
L	***H***	***L***	***0.284***	***0.716***	***0.257***	***0.743***
L	***L***	***H***	***0.2***	***0.8***	***0.2***	***0.8***
L	L	L	0	1	***0.18***	***0.82***

For example, the unknown value of $P(Z_H|A_HB_LC_L)$ can be estimated by multiplying the elicited value of $P(Z_H|A_HB_LC_H)$ by an interpolation factor (IF) that reflects the proportional change in conditional probability that is associated with changing parent variable C from High to Low (IF_C):

$$\mathrm{IF_C} = \frac{\left(\mathrm{P(Z_H|A_HB_HC_L)} - \mathrm{P(Z_H|A_LB_LC_L)}\right)}{\left(\mathrm{P(Z_H|A_HB_HC_H)} - \mathrm{P(Z_H|A_LB_LC_L)}\right)} = \frac{(0.9-0)}{(0.95-0)} = 0.947$$

Equation 1

$$\mathrm{P(Z_H|A_HB_LC_L)} = \left[\mathrm{P(Z_H|A_HB_LC_H)} - \mathrm{P(Z_H|A_LB_LC_L)}\right] \times \mathrm{IF_C} + \mathrm{P(Z_H|A_LB_LC_L)}$$
$$= [(0.7-0) \times 0.947] + 0 = 0.663$$

Equation 2

In the same way, IF_C can also be used to estimate $P(Z_H|A_LB_HC_L)$:

$$\mathrm{P(Z_H|A_LB_HC_L)} = \left[\mathrm{P(Z_H|A_LB_HC_H)} - \mathrm{P(Z_H|A_LB_LC_L)}\right] \times \mathrm{IF_C} + \mathrm{P(Z_H|A_LB_LC_L)}$$
$$= [(0.3-0) \times 0.947] + 0 = 0.284$$

Equation 3

An interpolation factor can also be computed to reflect the proportional change in conditional probability that is associated with independently changing the states of parent variable B:

$$\mathrm{IF_B} = \frac{\left(\mathrm{P(Z_H|A_H B_L C_H)} - \mathrm{P(Z_H|A_L B_L C_L)}\right)}{\left(\mathrm{P(Z_H|A_H B_H C_H)} - \mathrm{P(Z_H|A_L B_L C_L)}\right)} = \frac{(0.7 - 0)}{(0.95 - 0)} = 0.665$$

Equation 4

This can, in turn, be used to estimate the remaining unknown conditional probability value:

$$\mathrm{P(Z_H|A_L B_L C_H)} = \left[\mathrm{P(Z_H|A_L B_H C_H)} - \mathrm{P(Z_H|A_L B_L C_L)}\right] \times \mathrm{IF_B} + \mathrm{P(Z_H|A_L B_L C_L)}$$

$$= [(0.3 - 0) \times 0.665] + 0 = 0.20$$

Equation 5

Cain's (2001) method has similar assumptions as Noisy-OR (Onisko *et al.*, 2001; Fenton *et al.*, 2007): monotonicity and conditional independence of parent variables, although the parameterisation is slightly different. In this study, the assumption of monotonicity is supported by the fact that all of the elicited conditional probabilities conformed to this structure. The assumption of conditional independence is more problematic as in reality, complex, joint dependencies between parent variables are likely. However, factoring in such dependence requires more sophisticated interpolation methods that can model the form(s) of the joint dependencies and their influence on the conditional probabilities of the child variable states. Necessarily, some information about the form of the joint dependencies is required and in the context of participatory modelling, this would need to be directly elicited from participants. In many cases, it is unlikely that these forms will be known with sufficient specificity to inform such methods. Indeed, in Hebden Bridge the acceptance of implied independence between parent variables was a pragmatic solution to the participants' limited ability to express and formalise these joint dependencies.

Before using the model to explore flood risk intervention options in Hebden Bridge the participants completed a model calibration activity in Workshop 5 (effectively a version of Edwards (1998) 'antecedent conditions check'). The aim of this activity was to check that the behaviour of the final model conformed to the hypothetical expectations of the participants, enabling erroneous model behaviours to be traced and, where necessary, rectified by adjusting the state values of the variables implicated. Each intervention represented in the BNM was ranked according to its expected impact on each of the objectives and the rankings were tabulated by the participants. The states of each intervention were then set to effect the maximum possible positive change in the objectives (i.e. probability of 0 / 1 was applied) and the rank of the observed impact on each objective was added to

the tabulation. Where discrepancies in the rankings occurred, participants were asked to comment on the reasons for them, and suggest any adjustments that the BNM required. An example for two of the interventions in the social model component is provided in Table 5. Between Workshops 5 and 6, University of Nottingham researchers calibrated the variable state values where large discrepancies in the rankings were observed.

Table 5: Example output from model calibration activity

Interventions	Objectives	Preparedness and public safety	Flood damage	Flood consequences	Flood risk
Communication with residents	Ranked expected change	1	2	3	4
	Ranked observed change	1	4	2	3
	Comments: *Unclear definition of flood damage compared to consequences.* *We feel residents can have only limited impact on protecting themselves compared to public agencies.*				
Awareness campaign	Ranked expected change	1	= 2	= 2	3
	Ranked observed change	4	2	1	3
	Comments: *Odd that awareness campaign doesn't change preparedness.* *Could this be a problem with the original concept (e.g. awareness campaign vs. communication with residents)?*				

6. Using the model to support intervention options identification (Stage 3)

The reasoning capability of the BNM was used to infer the relative dependence of each intervention in delivering each FRM objective via a one way sensitivity analysis (Coupe, 2001). Assuming a simple case of a binary child variable C with two binary parents A and B (all with states High and Low), the marginal probability of C_H can be computed according to the law of total probability:

$$P(C_H) = P(C_H|A_H \cap B_H) + P(C_H|A_L \cap B_H) + P(C|A_H \cap B_L) + P(C|A_L \cap B_L)$$

Equation 6

The conditional probability of C, given A and B can be also be computed from the joint, conditional probability distribution for the two objectives (A and B):

$$P(C_H|A_H \cap B_H) = \frac{P(A_H \cap B_H \cap C_H)}{P(A_H|B_H) \times P(B_H)}$$

Equation 7

Using Bayes law, it is then possible to compute the conditional probability of A given C:

$$P(A_H|C_H) = \frac{P(A_H \cap C_H)}{P(C_H)}$$

Equation 8

Similarly, it is possible to compute the conditional probability of B given C:

$$P(B_H|C_H) = \frac{P(B_H \cap C_H)}{P(C_H)}$$

Equation 9

Equations 8 and 9 can be used to assess the sensitivity of variables in a Bayesian network by back-propagating the effect of changing the states of a child variable on its parents. Take, for example, Figure 10 which shows a fragment of the Hebden Bridge BNM. The objective 'Flood damage' (C) is conditionally dependent on two interventions - 'Take up of flood action plan' (A) and 'Take up of property level protection' (B) (Figure 10).

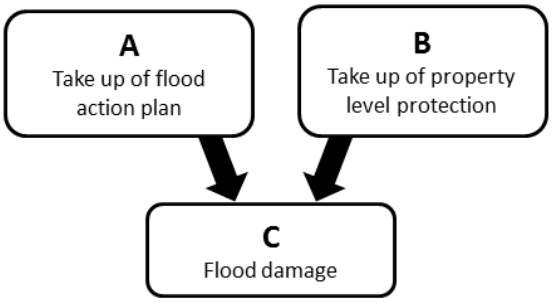


Figure 10: A simple directed acyclic graph for structuring flood risk interventions (A, B) and their causal relationship with the flood damage objective (C)

The sensitivity of intervention A (A_{sen}) to the objective C can be assessed by quantifying the effect that change to the states of C has on the states of A:

$$A_{sen} = P(A_H|C_H) - P(A_H|C_L)$$

Equation 11

Similarly, the sensitivity of intervention B (B_{sen}) to the objective C can be assessed by quantifying the effect that change to the states of C has on the states of B:

$$B_{sen} = P(B_H|C_H) - P(B_H|C_L)$$

Equation 12

Using this approach, the strength of dependency between each intervention-objective couplet was assessed in turn by comparing the relative magnitude of their respective sensitivities. For each objective, the five interventions with the strongest dependence are presented in Table 6, together with their respective sensitivity values. It can be seen, for example, that reducing the storm water on roads and paths is highly dependent on the effectiveness of drain maintenance and the diversion of surface water. Similarly, it can be seen that the sensitivity of interventions to certain objectives (e.g. volume of surface runoff) is consistently low; indicting that the participants have low confidence that the objective can be achieved through the interventions that they have identified in the network. It should be noted that this approach assesses sensitivity of the simplified marginal probability (as defined in Equation 7) associated with each individual variable's states. It may be useful to extend this to include an assessment of the joint probabilities of variable states so that the priority combinations of interventions could be explored.

From the perspective of options identification, the relative magnitude of the sensitivity of each intervention to flood severity or consequence is of primary interest as this reveals the relative importance of each intervention in reducing the overall flood risk. The results for Hebden Bridge are presented in (Figure 11). Two features are particularly apparent. Firstly, the participants had the greatest confidence that interventions focussed on the modification of the river channel would have the greatest impact on reducing the severity of flooding, although there was limited confidence in the impact of more effective land and infrastructure management. Similarly, the participants had the greatest confidence in the beneficial role of awareness campaigns, effective planning and property level protection for reducing flood consequence. Secondly, the relative magnitude of the sensitivity of interventions concerned with reducing the severity of a flood event, versus those concerned with reducing flood consequence, highlights the overriding confidence afforded to interventions aimed at enhancing flood resilience in Hebden Bridge. Indeed, this highlights the importance of including interventions aimed at reducing flood vulnerability in future options appraisal processes for the town,

alongside those aimed at reducing flood likelihood, and the support that local stakeholders are likely to have for this.

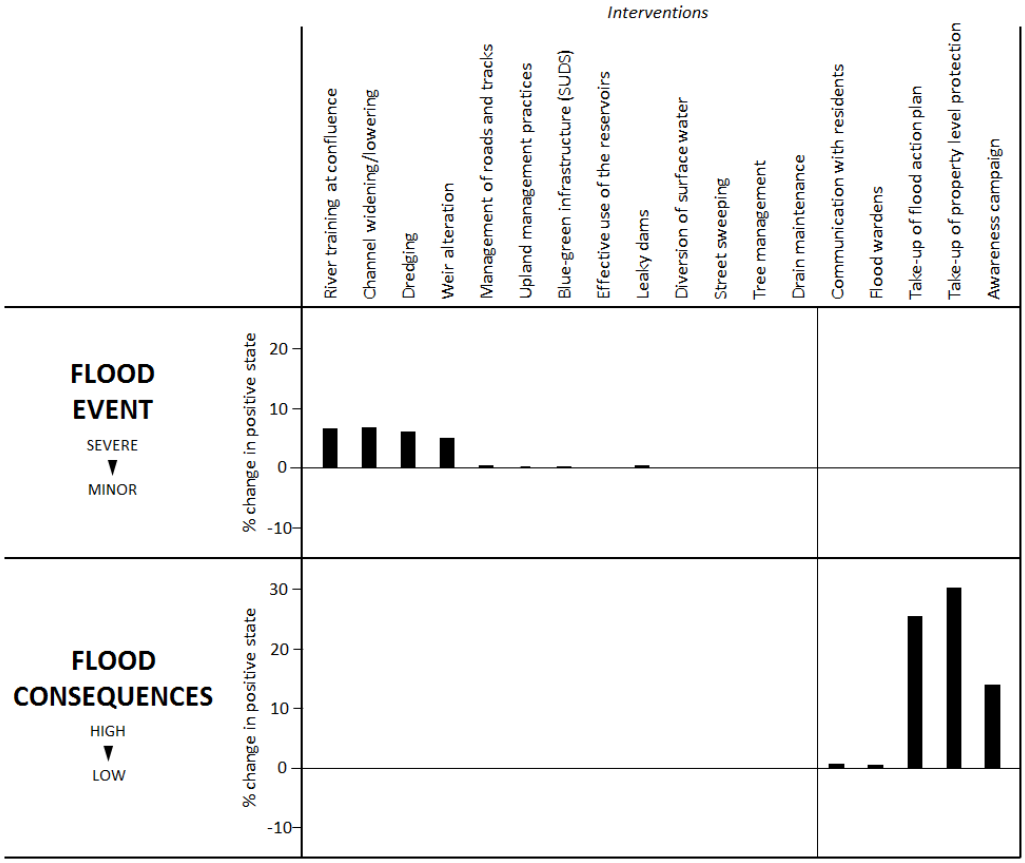


Figure 11: Sensitivity of interventions for the minimisation of flood event and consequence variables

Table 6: Results of using backwards propagation to test the sensitivity of each objective to different interventions. Percentages show the change observed in the desired state of each intervention.

	Sensitivity of interventions (percentage change in desired state)				
Objective	1	2	3	4	5
Speed of surface runoff	Leaky dams	Diversion of surface water	Drain maintenance	Management of roads and tracks	Upland management practices
	(26.8%)	(7.0%)	(6.3%)	(5.2%)	(2.6%)
Volume of surface runoff	Management of roads and tracks	Upland management practices	Blue-green infrastructure (inc. SUDS)	Diversion of surface water	Leaky dams
	(6.4%)	(3.3%)	(2.8%)	(2.7%)	(1.2%)
Interception	Blue-green infrastructure (inc. SUDS)	Upland management practices			
	(20.0%)	(12.3%)			
Stormwater on roads and paths	Diversion of surface water	Drain maintenance	Tree management	Street sweeping	Leaky dams
	(31.3%)	(28.2%)	(4.8%)	(3%)	(1.8%)
Surface storage	Diversion of surface water	Leaky dams	Blue-green infrastructure (inc. SUDS)	Effectiveness of using the reservoirs	
	(26.4%)	(11.6%)	(8.7%)	(6.7%)	
Community preparedness	Take-up of flood action plan	Communication with residents	Flood wardens		
	(25.3%)	(17.0%)	(11.5%)		
Flood damage	Take-up of property level protection	Take-up of flood action plan	Awareness campaign		
	(49.9%)	(41.6%)	(18.5%)		

7. Participatory modelling evaluation framework

The evaluation framework used to assess the participatory modelling process was derived by conflating the frameworks of Beierle (1999), Rowe and Frewer, (2000) and Webler and Tuler (2002) so that the benefits and drawbacks of i) the process itself and; ii) its outcomes were assessed (Figure 12).

7.1 Process evaluation

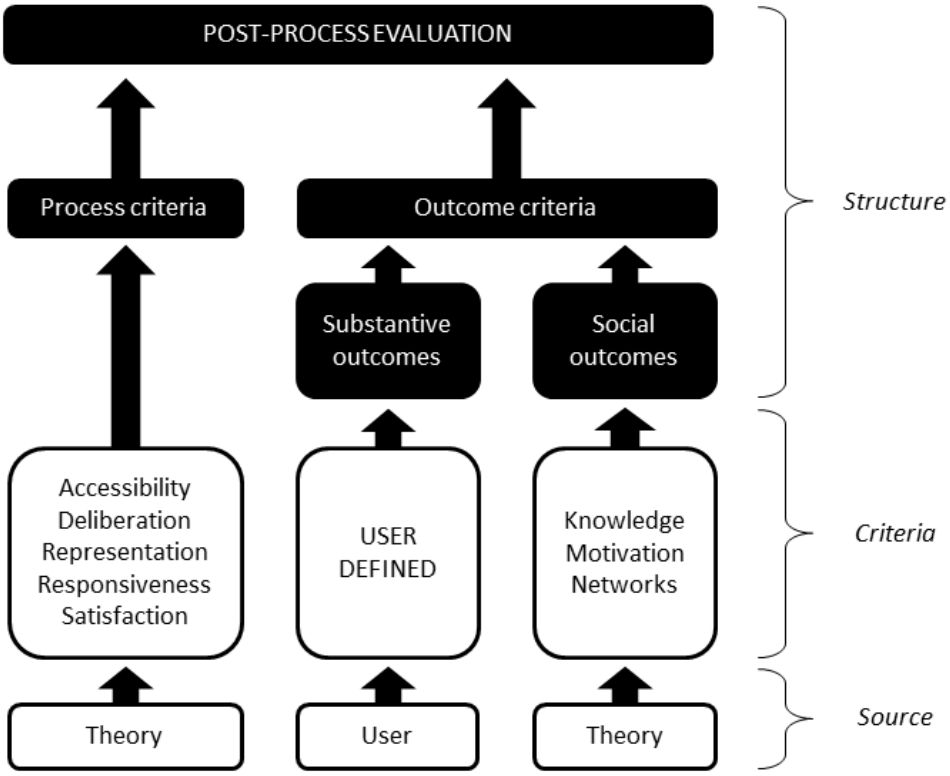


Figure 12: The framework used to evaluate the participatory modelling process in Hebden Bridge showing the sources of evidence from which criteria were developed

Normative and instrumental benefits (see Section 2) of the participatory modelling process were evaluated against 'Process Criteria' (Figure 12) which assess the process itself and the extent to which the organisation, activities and tools used were able to support the active participation of all participants in model co-production and testing (*cf.* Fiorino, 1990; Beierle and Konisky, 2000; Halvorsen, 2001; Butterfoss, 2006). They are synthesised from > 30 published evaluations of participatory modelling processes conducted across a diverse range of disciplines and are listed and described in Table 7, along with the literature from which they are synthesised.

Table 7: Criteria and findings from process evaluation

Criterion	References	Key findings
ACCESSIBILITY 1. Participatory activities, resources and language were designed such that all participants could fully engage, regardless of skills and experience 2. Clear and frequent communication kept the modelling process transparent	Godschalk and Stiftel (1981); Rowe and Frewer (2000); Abelson *et al.* (2003); Hare *et al.*, 2003; Prell *et al.*, 2007; Ramsey (2009)	• Fundamental concepts understood • Requires expert facilitation • Method and model accessible to non-experts • Stakeholder communications between workshops were effective
DELIBERATION 3. Participatory activities fostered knowledge exchange, debate and consensus building	Susskind and Cruickshank (1987); Kemmis (1990); Dryzek (1997); Smith and Wales (1999; 2000); Beierle and Konisky (2000); Halvorsen (2001); Abelson *et al.* (2003); Hartig *et al.*, 2010.	• Useful to hear each other's views • Model building generated discussion • Group started to build consensus
REPRESENTATION 4. The participants are representative of the affected community and the full range of views 5. All participants were given opportunity to make a substantive contribution	Crosby, 1995; Phillips, 1995; Webler (1995); Hartig *et al.* (1998); Beierle (1999); Smith and Wales (1999; 2000); Halvorsen (2001); Abelson *et al.* (2003); Butterfoss (2006).	• Group was not totally representative of community • Although residents were recruited, most participants were representatives of organisations • Discussions were open • Process gave participants an equal standing
RESPONSIVENESS 6. Participatory tools were chosen according to local objectives, resources and available data 7. The participatory process was flexible to change, with the agenda and activities shaped by the needs and goals of the participants	Fiorino (1990); Webler (1995); Beierle and Konisky (2000); Prell *et al.*, (2007); Voinov and Gaddis (2008); Ramsey, (2009); Voinov and Bousquet (2010).	• Model generally based on opinions of those participating • Process identified key variables • Possible to see own input in the model • Model allowed testing of scenarios

SATISFACTION 8. Participatory processes were facilitated in a professional and effective manner 9. The participants knew what was expected of them and what they could expect to gain from participating 10. The process had clear purpose, objectives and direction	Rogers *et al.* (1993); Hartig *et al.* (1994); Butterfoss *et al.* (1996); Beierle (1999); Chess and Purcell, 1999); Kenney *et al.*, (2000); Halvorsen (2001); Butterfoss (2006)	• Tasks were well-structured • Thinking time was provided between workshops • Process required a large (but not unreasonable) time commitment • Process became clearer the more sessions one attended • A useful addition early in the flood risk management process • Process became clearer the more sessions one attended

Criteria 1 and 2 relate to the accessibility of the process: its ability to involve a wide range of stakeholders in model development and calibration, through simple graphical interfaces and low complexity methods (Webler *et al.* 2001; Prell *et al.* 2007; Ramsey, 2009). Where responses focussed on the accessibility of the activities, resources and language used (Criterion 1), most respondents found that they easily grasped the fundamental concepts, and that this basic level of understanding was sufficient to benefit from participating. Generally, participants found that effective communication outside of the workshops supported accessibility. It was noted that additional resources (e.g. user manual) would be required to support use of the model outside of the process.

Criterion 3 relates to the extent to which the process is deemed to be deliberative, measured by the quality of communication within the participatory group, the degree to which consensus is sought, and the fairness of discussions (Beierle and Konisky, 2000). Several respondents valued the opportunity to hear one another's views, and noted that the discussions held during model co-production were one of the most useful process outcomes. While the group were uncertain on whether consensus was achieved, most responses suggested a move towards consensus, and a softening of extreme views.

Criteria 4 and 5 relate to whether the participant group and the resultant outcomes were representative of the community. Responses relating to the representativeness of the group (Criterion 4) suggest that the group was biased in favour of community stewardship, and lacked a desired balance between 'specialist' stakeholders and 'lay' residents. However, the participants that were involved with the process felt that they were able to engage in open discussion, in an environment where experts and non-experts worked alongside one another as equals (Criterion 5).

Criteria 6 and 7 relate to the responsiveness of the process: whether the approach and the tools used to support it were flexible to the needs of the participants, and the individual local context (Prell *et al.* 2007; Voinov and Gaddis, 2008). Participants commented on the ability of Bayesian networks to capture system complexities, conflicting opinions and management options; although it was contested as to whether these were specific to the Hebden Bridge area. They praised the holistic nature of the model for capturing the interconnectedness of the flooding issue, but believed that as the scope of the model widened, the solutions it proposed became less specific.

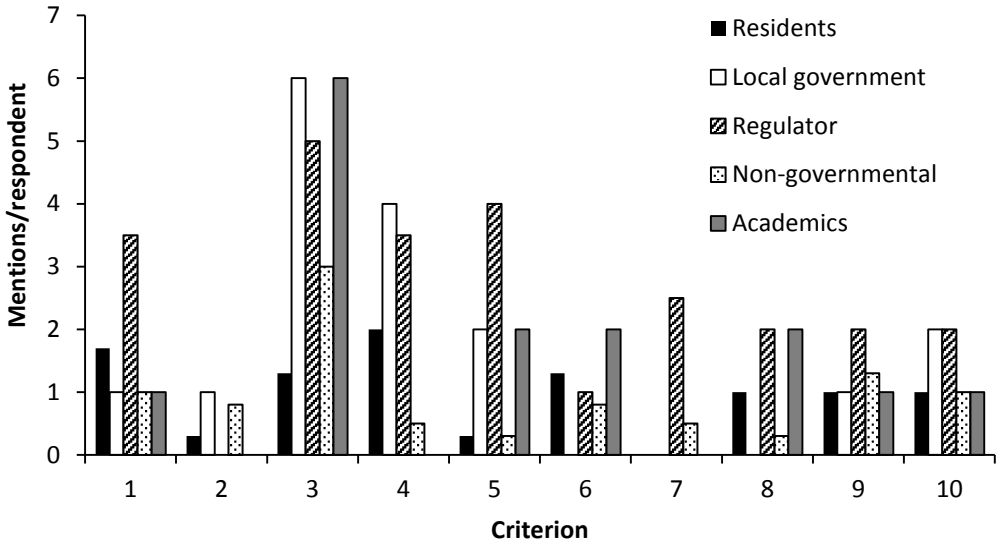


Figure 13: Mentions per participant group
(ordered by criterion) (for criteria see Table 7)

Much of the difficulty in designing participatory processes stems from the way in which different participant groups define the process as effective (Figure 13). For example, the views of residents (a particular group which active participation seeks to involve in the modelling process) are not always aligned with those of other groups. Specifically, residents rarely referred to knowledge exchange and deliberation (Criteria 3 and 5), implying either that these activities were not highly valued, or that the process could have delivered these better by being more accessible to non-experts. In contrast, local government and regulator mentions for both of these criteria (in addition to Criteria 7) were high, suggesting that they value these activities as central to an effective participatory process, but have overestimated the accessibility of this particular case, possibly as a result of their broader experience and expertise. Finally, Figure 13 illustrates the importance ascribed to having a modelling group which is representative of the local community (Criterion 4). Individual comments from interviews suggest that most respondents felt the group could have been more representative.

7.2 Substantive outcomes evaluation

Substantive outcome criteria assess the outcomes of the participatory process against those with the primary responsibility for implementing its results, with particular emphasis on the ability of the process to deliver evidence. In Hebden Bridge, substantive outcome criteria assess the extent to which the participatory model facilitated the identification of new intervention options that could feed into a subsequent appraisal process (i.e. substantive benefits). These were developed from iterative, *in vivo* coding (Given, 2008) of transcripts of semi-structured interviews (n=4) with staff at the Environment Agency (EA) and Calderdale Metropolitan Borough Council (CMBC), the principal flood risk management decision-makers for Hebden Bridge. These criteria, along with key findings, are presented in Table 8.

Table 8: Criteria and findings from substantive outcomes evaluation

Criterion	Mentions by organisation		Key findings
	EA	CMBC	
Model is accessible and available to those outside of the participatory group	13	1	• Model should be made available as an educational tool • Software is generally easy to use, but would require supporting documentation
Flooding is seen as a complex issue with multiple solutions	9	6	• Process raised awareness of the complex nature of flooding • People are generally better informed about flood risks • Process identified options that could be explored further
Residents gain an understanding of how to reduce their own flood risk	2	5	• Model showed various actions an individual could take • Process encouraged generation of ideas for small-scale solutions
Community priorities were highlighted	4	1	• Results from the process could be useful for agenda setting • Useful when strategic thinking is the main objective
General public has realistic expectations of agencies	9	5	• Difficult to measure whether expectations have changed
Residents understand they have a personal responsibility	1	5	• Process demonstrated a need to share responsibilities • Surprise at level of community enthusiasm and unity

Flooding is maintained as a priority in the community	3	3	• Interest in flooding remains several years after event
Participation is increased or maintained	14	11	• Process took participation to a higher level • Feedback from the process was positive • Impact on participation small compared to a flooding event
Individual action (change in behaviour) was promoted and taken up	4	3	• Change in behaviour attributed to a gaining of knowledge • Slight increase in adoption of property level protection
Community action (change in behaviour) was promoted and taken up	3	4	• Existing groups are now open to new ideas, as a result of what they have learnt • People now look at the multiple benefits of their actions (including reducing flood risk)

Representatives from the EA identified three main benefits. The first was the accessibility and availability of the model as an educational tool, and its potential for use by those not involved with its generation. The second concerned the improvement in each participant's understanding of the complexities of flooding and an appreciation of the need for multiple and innovative interventions. The third considered the identification of community priorities for the management of flooding. On several occasions, respondents suggested that results from the participatory modelling process could be used to inform and guide other flood risk management activities that do not have such an active level of participation.

Representatives from CMBC focussed on flood resilience in the community. Responses centred on residents gaining an understanding of actions they can take to personally contribute towards a reduction in flood risk; building the capacity to take those actions; and fostering a sense of personal responsibility to do so.

7.3 Social outcomes evaluation

The extent to which the participatory modelling process facilitated new knowledge and understanding of local flood risk processes and interventions amongst the participants engaged in its co-production

(i.e. delivered instrumental benefits through its agency as a facilitator of beneficial social change and enhanced community resilience (e.g. Cutter *et al.*, 2008)) was assessed using 'Social Outcome Criteria. These were derived from > 15 studies exploring the relationship between three components of social capacity (knowledge, motivation and networking (Buchecker *et al.*, 2013)) and community resilience (Kuhlicke *et al.*, 2011), and structured using Buchecker's three components of social capacity. These criteria, along with key findings, are presented in Table 9 and Figure 14.

Table 9: Criteria and findings from social outcomes evaluation

Criterion	References	Key findings
KNOWLEDGE CAPACITY 1. Participants shared in the coproduction of knowledge on local flood risks (including hazard, exposure and vulnerability) 2. Participants discussed their perceptions of risk, and explored a range of interventions that could mitigate them 3. Participants know who to go to for support within and outside of the community, and feel better prepared for another flood event	Folke *et al.* (2005); Howgate and Kenyon (2009); Nobert *et al.* (2010); Höppner *et al.* (2012); Buchecker *et al.* (2013)	• Stakeholders learnt from each other • Awareness raised of importance of local knowledge • Potential for generating novel and innovative solutions • Model allowed exploration of different interventions • Useful opportunity to talk with experts • Useful to meet and get to know other stakeholders
MOTIVATION CAPACITY 4. Participants feel motivated to take ownership and responsibility for taking a proactive role in the reduction of local flood risk 5. Participants identified a range of appropriate interventions that could be implemented by either individuals and/or the community	De Long and Fahey (2000); Uphoff (2000); O'Neill (2004); Deeming (2008); Buchecker *et al.* (2013)	• Empowers local people to get more involved • Flood resilience came through as a strong theme • Model looked beyond the usual interventions • Developed understanding that there was no single solution

NETWORK CAPACITY 6. Relationships were developed between participants from both within and outside of the local flood risk community 7. Trust was developed between participants from both within and outside of the local flood risk community	Putnam (1993; 2000); Pelling (1998; 2003); Ardichvili *et al.* (2003); Folke *et al.* (2003); Chazdon and Lott (2010); Buchecker *et al.* (2013)	• Stakeholder relationships were improved • Useful way of getting stakeholders to work together • All participants were seen and treated as equals • Discussions were open and people were willing to listen

Criteria 1 – 3 relate to knowledge capacity: the efficient use and sharing of knowledge within a community that empowers individuals to work effectively in teams, establishes information channels, increases risk perception, and enhances a sense of personal control (Beretta, 2005; Höppner *et al.* 2010; 2012). Responses highlighted the value participants placed on sharing local knowledge, and using that knowledge to build better models (Criterion 1). These discussions encouraged participants to think about multiple risks, the interconnectivity of system elements, and novel solutions that could help to reduce flood risk (Criterion 2). Further, it facilitated stakeholder networking, promoted positive engagement between practitioners and residents, and helped improve understanding of different stakeholders' roles (Criterion 3).

Criteria 4 and 5 relate to motivation capacity: the existence of established norms that promote trust, where active involvement in knowledge-exchange activities and support of community initiatives are seen as moral obligations (Hayes and Walsham, 2001; Ardichvili *et al.* 2003). Participants valued the opportunity that participation afforded them to get more involved in decision-making, share responsibilities, and take the lead on flood resilience issues (Criterion 4). The process further demystified the notion that there was one single solution to flooding in Hebden Bridge, that any solution would require a combination of appropriate interventions, many implemented by the community themselves (Criterion 5).

Criteria 6 and 7 relate to network capacity: the building of mutually beneficial social relationships between individuals and groups, both within and outside of the community, that foster feelings of social connectedness, support, resilience, and adaptability (Putnam, 1993; 2000; Folke *et al.* 2003; 2005). Participants saw the process as a useful means of getting individuals and organisations to meet, work together, and discuss their views and roles (Criterion 6). The building of trust (Criterion 7) was mainly discussed with reference to equality and openness between participants, allowing them to engage with new ideas.

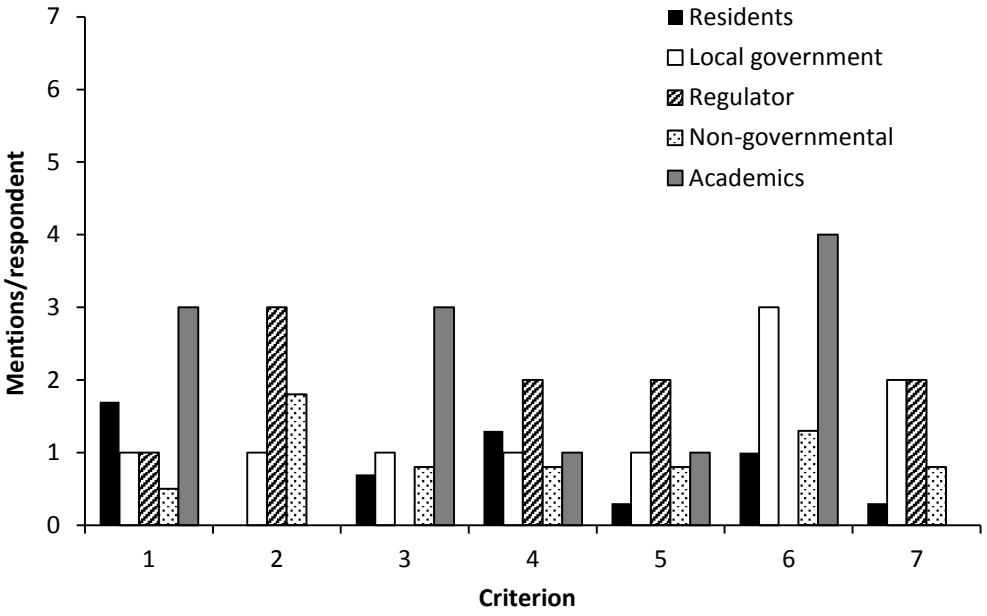


Figure 14: Mentions per participant group
(ordered by criterion) (for criteria see Table 9)

The ways in which different groups value the social outcomes of participatory processes further reinforce the different ways participants are framing participation in flood risk management (Figure 14). Both local government and non-governmental organisations felt that participation developed relationships both within and outside of the flood risk community (Criterion 6). As responsibilities are increasingly devolved to local levels, relationships between local organisations will become ever more important for effective FRM. In contrast, responses from the EA centred on identifying and exploring different flood risk interventions (Criteria 2 and 5), especially where members of the community can take a more active role in their implementation (Criterion 4); indicative of a need to move beyond traditional engineering solutions. Finally, the similarities in responses related to community intervention (Criteria 4 and 5) could suggest a shift towards (or a response to) the sharing of responsibilities.

8. Lessons for local flood risk management

While the importance of participation in environmental management is supported by legislative enthusiasm, it has largely remained limited to consultation in flood risk decision-making. Practitioners are understandably cautious about initiating more comprehensive participation. Advice and practical guidance on how to make flood risk modelling more participatory is sparse, and studies have shown that ineffective participation can damage relationships and trust. Yet, as the responsibilities and costs of managing flood risk are increasingly devolved to local levels and shared amongst a growing number of stakeholders (Thaler and Priest, 2014), participatory models offer a mechanism for involving a breadth of stakeholders in decision-making. Crucially, participatory modelling provides a means by which tacit and situated knowledge can be captured represented and used – an outcome that is increasingly seen as critical to mitigating flood consequences through the identification of social and behavioural solutions as well as engineered ones.

The study presented here challenges some of the common critiques of participation and participatory modelling. It contests the assertion that participation fosters a post-political condition with no space for conflict and disagreement (Tsouvalis and Waterton, 2012). The process evaluation revealed that knowledge exchange and debate was fostered, and that the participatory model development acted as a locus for consensus building. Similarly, the notion that flood risk is understood by non-experts as a series of unchallengeable 'facts' is demonstrably not the case in Hebden Bridge. Here, the participatory modelling processes provided an opportunity for the 'open public framing' (Wynne, 2007) of flood risk problems which is complementary to, yet discrete from the numerical models designed to quantify and reduce flood likelihood. Indeed, the substantive evaluation (Table 8) highlights how the approach is viewed as complementary to more established FRM activities and how the case study represents a valuable blueprint for other flood risk management activities. It also highlights the practitioners' recognition that small-scale interventions, enacted by individuals and/or the community have the potential to be extremely important interventions in local FRM contexts.

From a methodological perspective, the study reveals the efficacy of BNMs as tools for helping to assess the broadest range of potential options (many of which will be community-driven social solutions that are difficult to integrate into traditional numerical models) in a participatory options identification process. It also highlights its value as a means of exploring which of these might merit further examination. We assert that the strengths of the BNM method extend beyond the numerical outputs that are produced. They include the relative ease with which both explicit and tacit knowledge about flood risk cause and effect can be structured and formalised by stakeholders and the ability to reveal

misconceptions and gaps in this causal knowledge alongside insights into stakeholder perceptions of flood risk and solutions for addressing it. Both are of value to flood risk practitioners.

The study also highlights several important challenges. Working with a diversity of stakeholder participants inevitably involves a diversity of opinion and individual bias that may be impacted by the recentness with which flooding has been experienced. Methods need to account for the fact that the participants with the loudest voices do not necessarily possess the greatest knowledge. The evaluation we present highlights the extent to which a flooding event can act as an agent for mobilising the community (*cf.* Lane *et al.* 2011), but it does not reveal the optimum time to organise a participatory FRM process. The study also highlights that, where participants have limited technical and/or numerical capacity, very high levels of conceptual and numerical simplification must be applied to the representation of the local flood risk system if the participatory model is to be accessible and meaningful to the participants that develop it. In this case, simplification included the limitation of variables to qualitative binary states – reducing the resolution of the model and limiting the extent to which it could be informed by data. Despite this, the technique achieved its goal of informing a shortlist of intervention options for Hebden Bridge that warranted further appraisal which incorporated both social and behavioural as well physical / engineering interventions (Figure 11).

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III) Paper III.

Participatory modelling for stakeholder involvement to review community options for the building of flood risk resilience

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Abstract

Individuals and communities are increasingly becoming involved in the management of flood risk at local levels. Techniques are sought which enable these local stakeholders to actively engage with local decision-making processes, in order that the wealth of tacit knowledge on exposure and vulnerability they hold, is integrated with traditional models that focus primarily on the sources and pathways of flooding. This paper details the design and implementation of a participatory modelling process to support local stakeholders review existing, and explore new interventions, designed to improve community resilience to flood risk. A model utilising elements of system dynamics was co-produced by local stakeholders. The process and its outcomes were evaluated against criteria developed specifically for the assessment of participation in flood risk management. It concludes that participatory modelling techniques can be used to elicit and structure local knowledge and perception of flood risk, such that individual and community-scale interventions can be reviewed and future recommendations made.

Highlights

- Case study uses participatory modelling approach to involve local stakeholders
- Application of system dynamics to co-produce conceptual model of flood risk
- Testing of model with stakeholders to prioritise community interventions
- Process and outcomes evaluated using criteria specific to flood risk management
- Approach effective at reviewing existing interventions and making future recommendations

Keywords

Participatory modelling, system dynamics, flood risk management, stakeholder engagement, evaluation, community resilience

1. Introduction

The ability of people to assess flood risk and choose the appropriate strategies for reducing that risk is becoming an essential part of local flood risk management, particularly as responsibility for risk governance is increasingly being devolved downwards and outwards to Local Authorities and the general public (Steinführer *et al.* 2009). An added challenge for flood risk management is to actively build flood risk resilience in an environment characterised by an infrequent hazard, and to maintain that resilience over time (Paton *et al.* 2003).

As a result of semantic differences in how hazard terms are defined, this paper here defines resilience as 'the ability for a social system to respond and recover from disasters and includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event adaptive processes that facilitate the ability of the social system to re-organise, change and learn in response to a threat' (Cutter *et al.* 2008). Resilience is affected by vulnerability, here defined as 'the pre-event characteristics or qualities of a social system that creates potential for harm' (*ibid.*), which is a function of sensitivity (the degree to which someone or something is susceptible to harm) and exposure (who or what is at risk).

The barriers to enhancing flood risk resilience relate primarily to risk perception (failure to internalise the risk of a hazard) and coping appraisal (doubting one's ability to take action, and for one's actions to be effective) (see Section 2) (Dufty, 2010). Arguably these barriers are best overcome through active local participation that supports communities to develop their own plans for building flood risk resilience, which are tailored to the specific needs and priorities of their locality.

Although risk governance is traditionally premised on the information-deficit model (Hilgartner, 1990), assuming the public lack the *de facto* knowledge to make informed decisions and behave appropriately during flood events (Brown and Damery, 2002); a second form, participatory risk governance, focusses on a particular context and locality, driven by the demands of the residents to learn more about the risks they face (Kuhlicke *et al.* 2011). In this participatory setting, the role of risk educator may be taken by a range of actors (non-governmental organisations, local authorities, academics, etc…), who facilitate the building of social capacity for preparedness, response and recovery within a community. Members of the public are viewed as being far from ignorant and irrational in their understanding of risk, but as experts in their own right due to the tacit, situated knowledge they possess (*cf.* Irwin and Wynne, 1996; Wynne, 1996). Public participation has the potential to enhance flood risk resilience by building this capacity to prepare for, cope during, and 'bounce back' after a flood event; by ensuring that members of the community have the resources, knowledge and training required to efficiently and effectively utilise their physical and economic resources (Paton and Johnston, 2001). Diversity in the way perceived

risk is distributed through a community provides further complexity to its management, and can be managed by facilitating participation between local stakeholders (Kasperson, 1992).

The objectives of this paper are to:

(i) Exemplify how participation can be used to build flood risk resilience: specifically to better understand existing levels of resilience, and explore how resilience can be enhanced, particularly through reductions in the vulnerability of receptors perceived to be at risk.

(ii) Assess the extent to which system dynamics can be used as a participatory modelling tool to support local stakeholders integrate their knowledge of flood risk, better understand gaps in that knowledge, and use their combined understanding to review appropriate resilience interventions.

The approach is demonstrated using the case study of Southwell, Nottinghamshire, UK, which experienced large scale pluvial flooding in July 2013. As part of ongoing work to enhance flood risk resilience, elements of system dynamics were adopted to co-produce a model with members of Southwell Flood Forum (local interest group), Nottinghamshire County Council (the Lead Local Flood Authority (LLFA)) and other local stakeholders. A detailed evaluation of the participatory modelling approach and tool used highlights how participation can enhance local flood risk resilience, through the assessment of community interventions.

The remainder of this paper is structured as follows. Stakeholder participation is explored in Section 2, with a particular focus on its application in the governance of flood risk. Section 3 introduces the three-stage participatory approach adopted in Southwell, which forms the basis of the methodology detailed in Sections 4, 5 and 6. An evaluation framework is outlined in Section 7, informing a detailed evaluation of the process and its outcomes in Section 8. Finally, Section 9 concludes the paper with a brief account of the lessons learnt in applying participatory techniques to flood risk management.

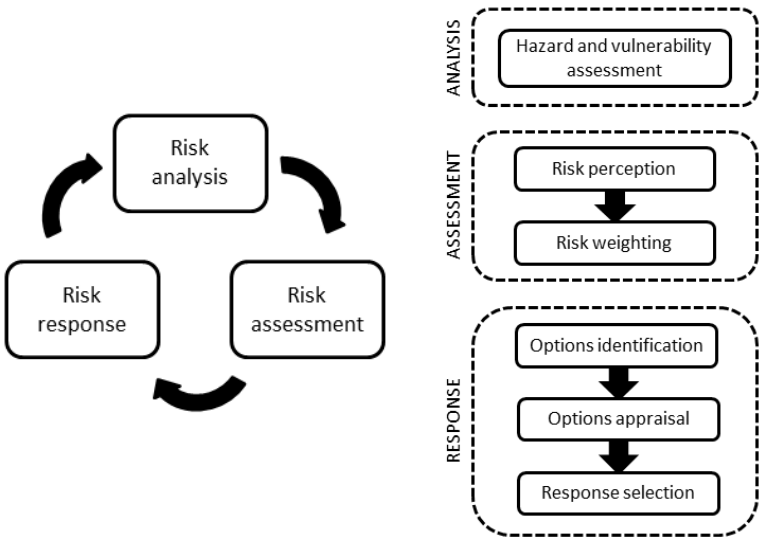
2. Stakeholder participation in the understanding and governance of local flood risk

Over the last two decades the governance of risk has undergone a transformation, departing from the traditional view stressing the primacy of scientific knowledge, and its objectivity as the means to managing environmental problems, to valuing the involvement of stakeholders in its risk assessment and management (Rhodes 1997; Jasanoff, 1998; Bevir *et al*., 2003). Rationales for this transformation include the changing understanding of risk (risks deemed to be more uncertain; greater appreciation of

the limitations of science), and wider societal changes characterised by a 'rolling back of the state' and the involvement of new actors in decision-making (Walker *et al.* 2010). Risk governance in the European Union, guided by policy documents such as the Water Framework Directive (EC, 2000) and Floods Directive (EC, 2007), has seen devolution of power to, and the promotion of participation at, the local level (for a UK example see DEFRA, 2008). This has been characterised by some as the 'privatisation of risk', whereby those at risk are transformed into risk managers and active participants in risk governance (Steinführer *et al.* 2009).

At its most basic level, risk governance involves two primary tasks: a) generating and collecting knowledge about risk; and b) using that knowledge to make decisions about how to manage it. It forms an iterative cycle of risk analysis, risk assessment and risk response (Figure 1) (Renn, 2008; Schanze *et al.* 2007). Underpinning the cycle is a sound understanding of local risks and the social, institutional and political context in which they are located (Renn, 2008). Failure to account for this local variability can lead to blanket protocols that are insensitive to the local context. This is demonstrated by the case of Hebden Bridge, West Yorkshire, UK; which remains largely undefended despite experiencing frequent and significant flooding events. Previous plans to install engineered flood walls failed to take account of the impact that these structures would have on the aesthetic appearance of the town, and the tourist trade upon which its economy heavily relies – meeting with significant public disapproval and ultimately being shelved. Active public participation in renewed attempts to manage flood risk in the town is helping to build consensus around alternative solutions that take account of multiple local objectives.

Figure 1: Risk governance cycle and key tasks (after Renn, 2008; Schanze *et al.* 2007)



While flood risk governance has always involved the activities of various actors and coordination between multiple public services, voluntary, and community organisations (*cf.* Christoplos *et al.* 2001), participation is rarely seen in its early stages (Figure 1). Risk analysis and assessment determine those risks that are deemed salient and thus targeted for management. Managed effectively, participation in these early stages can greatly enhance people's willingness to actively manage rather than deny risks (O'Neill, 2004). The critical role played by risk assessment in personal motivation to protect against flooding is highlighted in Figure 2 (*cf.* Rogers, 1983; Rogers and Prentice-Dunn, 1997).

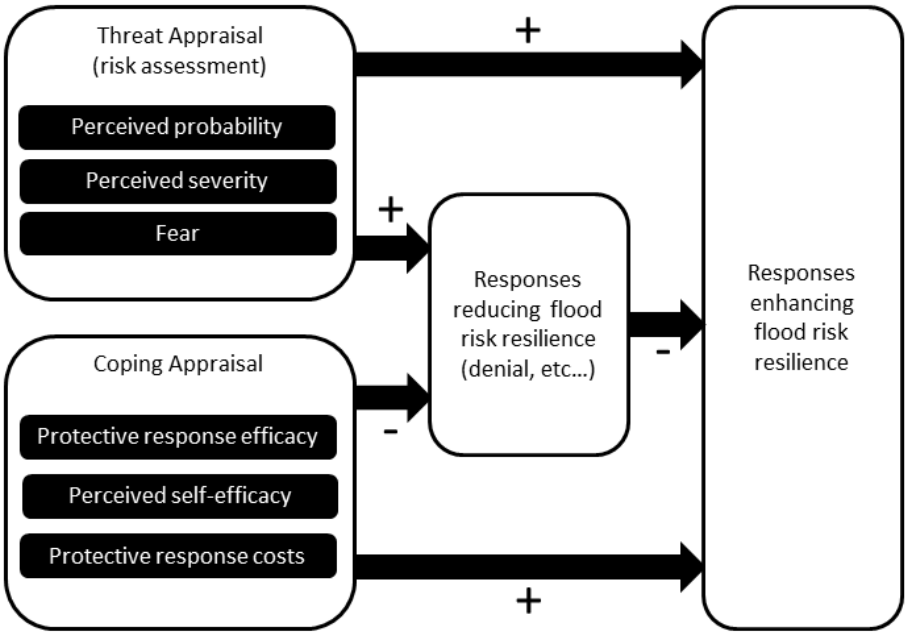


Figure 2: Factors affecting responses to flood risk (modified after Grothmann and Reusswig, 2006)

The model describes how threat and coping appraisal alter an individual's responses and hence their levels of resilience. Threat appraisal, is an individual's risk assessment of the probability and damage potential of a threat. Coping appraisal is a function of protective response efficacy (believing that actions will work), perceived self-efficacy (believing that one can carry out protective actions), and protective response costs (monetary cost, time and effort). High levels of threat appraisal can promote either action or inaction (Milne *et al.* 2000), with protective responses only becoming preferential once coping appraisal is sufficiently high (Grothmann and Reusswig, 2006). If risk governance is changing in nature from finding technical solutions and providing emergency recovery to promoting local preparedness and resilience, then it must address the barriers to self-protecting behaviour and foster an environment which promotes it.

Whether increasing participation results in positive changes in environmental risk governance remains a subject of debate (*cf.* Hajer and Versteg, 2005). Potential benefits include an increase in democracy, with greater opportunities for the public and other marginalised groups to become actively involved in decision making (Rosenau, 2004); bringing more actors to the table, and hence a greater diversity of perspectives (Marks and Hooghe, 2004); and widening of the knowledge base. Where expert knowledge continues to dominate the early stages of risk governance (Figure 1), risk assessment is focussed on the hazard, with only limited assessments of impact and vulnerability (Walker *et al.* 2010). However, greater numbers of voices does not necessarily mean that more views will be listened to and valued. The risk exists that power will remain with those actors who have the leverage to ensure that outcomes are favourable for them (Bache, 1999; Pelling, 2003; Guy Peters and Pierre, 2004). If this power is abused, then it will become harder for the decisions (that were once made by elected officials) to be challenged (Rhodes, 1997).

3. Study site and participatory process overview

Southwell is an affluent rural town (population 7,000) situated 15 miles northeast of Nottingham, UK (Figure 3). The town centre is located at the base of a shallow basin where the Potwell Dyke and other minor water courses confluence with the River Greet (catchment size 46.2km^2, mean discharge ~0.31 m^3 s^{-1}). Southwell is covered by two hydrologically distinct sub-catchments. The Potwell Dyke (catchment size 5.86km^2) runs through the southern part of Southwell, draining a rural arable catchment with clay soils. Upon entering the town, the watercourse is crossed by multiple road and foot bridges, and passes through culverts that present severe restrictions to flow (AECOM, 2015). A second sub-catchment, Halam Hill (catchment size 2.15km^2), covers the northern part of the town, consisting of several ordinary watercourses having their headwaters in a large country park and golf course. Flow is regulated by a balancing pond before being culverted for most of its urban course. The combination of geology and topography result in a flashy response to summer convective storms. In addition, runoff from the catchment during periods of localised heavy rainfall contributes to incidences of pluvial flooding. Southwell experienced major flooding from the Potwell Dyke and other minor water courses on 23 July 2013, after a storm cell developed over central Nottinghamshire, recording 93mm of rainfall in 75 minutes (Figure 4) (*ibid.*).

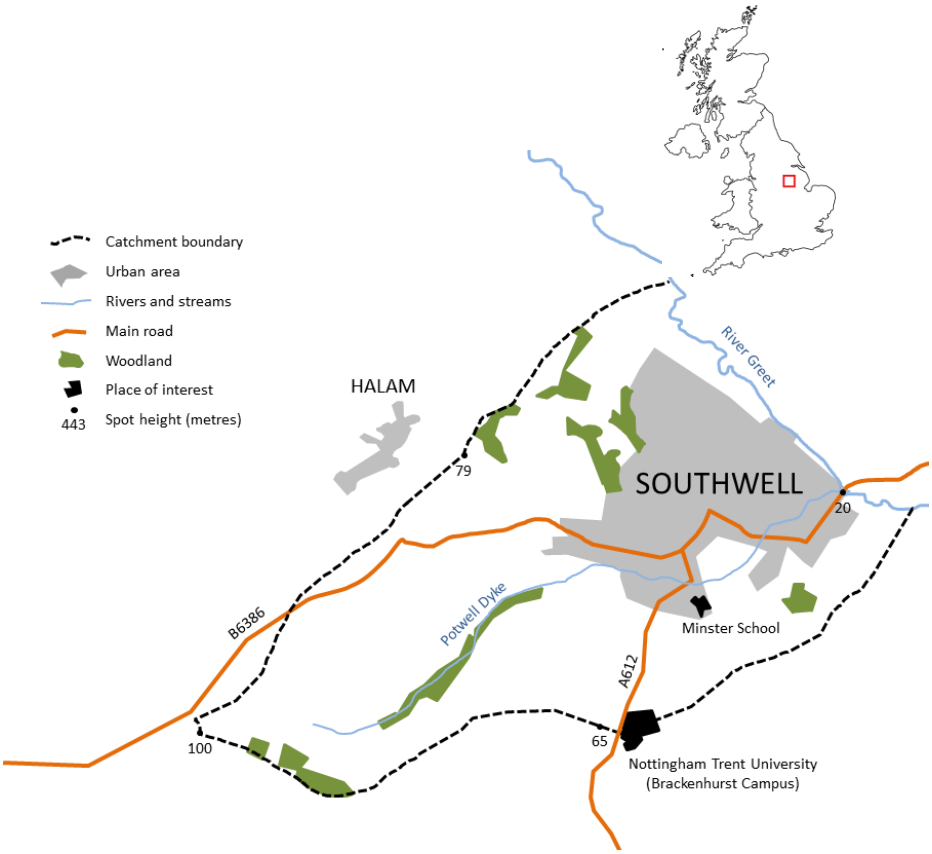


Figure 3: Southwell and surrounding catchment, with inset locator map



Figure 4: 23rd July 2013 flood event in Southwell (courtesy Southwell Flood Forum)

The summer 2013 flood was primarily pluvial in nature, causing widespread surface water flooding and an overwhelming of the Potwell Dyke. Responsibility for managing flood risk from the Potwell Dyke and the several ordinary watercourses that form the Halam Hill sub-catchment is shared among a number of stakeholders, including riparian owners, who have a responsibility for ensuring that the watercourse is kept clear of vegetation and debris in the section that runs adjacent to their property. When these responsibilities were clarified after the event, the community began to take a much more active approach to the management of flood risk.

Affected residents formed Southwell Flood Forum, a local action group who act as a 'representative voice for [the] community and … aim to work in partnership with the Agencies and Authorities whose work involves flood risk' (National Flood Forum, 2016). The Forum has become an essential source of information and support for local residents, a voice for their concerns and aspirations, and a driver of community action (Southwell Flood Forum, 2016). Following the event, Nottinghamshire County Council contracted environmental consultants AECOM (formerly URS) to conduct hydraulic and hydrological modelling, with the goal of informing options appraisal. Funding was secured in December 2014 for a potential of £720,000 grant in aid funding from central government, with an additional £830,000 from public contributions and £125,000 raised by Southwell Flood Forum (AECOM, 2015). Throughout this process, residents continued to develop ways in which they, as a community, can contribute to increasing resilience and reducing their vulnerability to flooding.

Partnering with Southwell Flood Forum, and supported by input from expert stakeholders (Nottinghamshire County Council, the Environment Agency, Severn Trent, etc.), a group of local residents were recruited into a modelling group with the aim of gathering together local understanding of what receptors were at risk during the 2013 event, how this risk responded to changes in floodwater depth, and how different community interventions might enhance the resilience of those receptors.

Recognising that local stakeholders with recent, first-hand experience of the processes and impacts of flooding in the town are an important resource of situated knowledge that can help identify and evaluate community interventions (Callon, 1999; RELU, 2010), it was decided that the process should be participatory and seek to enable the collaborative assessment of a broad range of community intervention options.

Specifically, the process aimed to:

1. Identify the different receptors at risk, based on participants' personal experience of the 2013 event and earlier flooding events in the community.
2. Assess the vulnerability of each receptor in terms of its sensitivity and exposure during the 2013 event (as defined in Section 1).
3. Explore how different intervention options (operational, planned, and potential) could reduce receptor vulnerability and therefore increase flood risk resilience.

To achieve these aims the participatory modelling process was structured into three stages (Figure 5):

Stage 1 An analysis of stakeholders with the situated knowledge necessary to explore the vulnerability of receptors at each of eight co-identified risk hotspot locations in Southwell (see Section 4).

Stage 2 The selection of a modelling approach and tool, and the co-production of conceptual flood risk resilience models that quantify flood risk resilience as a function of the vulnerability levels of all relevant receptors (see Section 5).

Stage 3 The application of the models to produce a series of risk curves for different locations in Southwell, which show how the risk to each receptor changes as a function of floodwater depth and its vulnerability. To use these curves to explore and assess how different community interventions might reduce vulnerability (and therefore enhance overall flood risk resilience) (see Section 6).

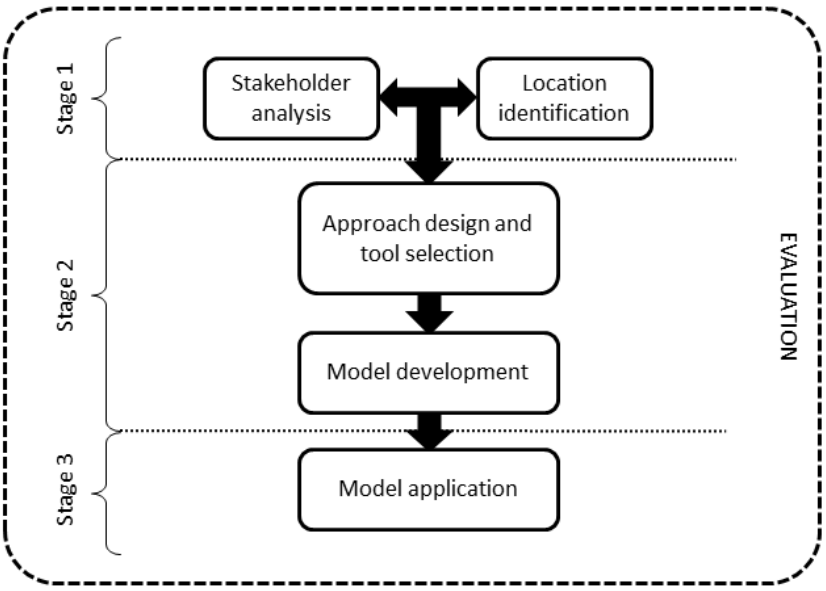


Figure 5: The structure of the participatory process used in Southwell

The process used elements of system dynamics to create temporal models for eight locations identified by participants as 'risk hotspots' in Southwell. System dynamics facilitated the modelling of temporal changes in the flood risk system, offering benefits over alternative techniques such as Bayesian networks, which provide a snapshot of the system at a given point in time (*cf.* Maskrey *et al.* 2016). Due to limitations in participants' understanding of the dynamics of the flood risk system and the complexities involved in attempting to model how different locations in the town are spatially connected, the models produced in this Southwell study do not involve feedback mechanisms either between or within locations (for further details on limitations see Section 5.3). However, they retain some temporal benefits of the technique by modelling how risk changes in response to the changing depths of floodwater during the course of an event. The primary outputs of the models are a series of risk curves, which express how perceived risk at different locations changes throughout a given flood event. These curves are the product of floodwater depth at that location, and the participants'

quantification of how receptor vulnerability changes in response to floodwater depth. To support model verification, floodwater depth estimates from the 2013 event (as modelled by AECOM), were used to allow stakeholders to evaluate whether the model captured their collective understanding and personal experiences of how different receptors responded during a recent event. Participants went on to use these risk curves as the basis to evaluate and compare how different interventions might reduce risk across the eight locations.

It is important to note that neither the participatory modelling process, nor the model it produced, were conceived as a replacement for the hydraulic, hydrologic and social models used to inform comprehensive options appraisal processes, (e.g. Evans *et al.* 2002; Sayers and Meadowcroft, 2005), but rather as a novel means of interfacing and integrating local stakeholders and practitioners in a way that could better support the review of community intervention options and the development of innovative new options for continuing to enhance flood risk resilience.

4. Stakeholder analysis and location identification (Stage 1)

With the participatory process aimed at identifying potential community interventions for maximising resilience, stakeholder analysis was driven by three key attributes:

1. Affection (the stakeholder group is representative of the affected community)
2. Expertise (the stakeholder group possesses the balance of situated knowledge and technical expertise necessary to model a combination of physical and social interventions)
3. Responsibility (the stakeholder group includes those who share the responsibility and power to ensure that any recommendations are taken forward for future appraisal)

To ensure the participant group met all three of these criteria, stakeholders were mapped using a stakeholder typology developed after Freeman (1984) and Mitchell *et al.* (1997) (Figure 6), and subsequent stakeholder selection focussed on those stakeholders exhibiting at least two of the three criteria. This analysis accommodates the move towards valuing different kinds of expertise (e.g. that held by expert practitioners and that held by expert locals).

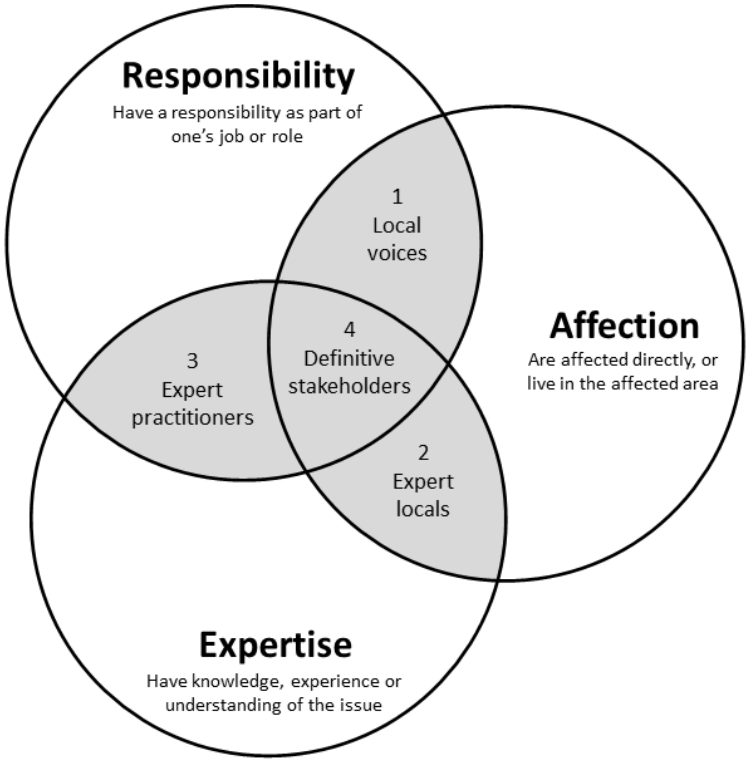


Figure 6: Stakeholder typology (after Freeman, 1984; Mitchell *et al.* 1997)

In the case of Southwell, a multi-agency partnership of local organisations with responsibility for managing flood risk had already been formed following the 2013 flood events. Through this established network, many of the stakeholders with expertise and responsibility were easily identified. Recruiting participants from the affection sector was achieved by partnering with Southwell Flood Forum, a local action group consisting primarily of affected residents. The Forum acted as a gatekeeper to recruiting additional members of the local community, and facilitated an iterative, top-down stakeholder identification methodology (Dougill *et al.* 2006; Prell *et al.* 2008), often referred to as 'snowballing' or 'referral sampling' (Harrison and Quershi, 2000; Hair *et al.* 2010).

Semi-structured interviews (n=20) were conducted with an initial set of stakeholders identified by the Forum. Interview transcripts were subsequently analysed to elicit additional stakeholders that should subsequently be contacted (i.e. referral through the network), and to build up an understanding of the receptors of flood risk in Southwell. A total of 35 stakeholders from 10 separate organisations / groups agreed to participate in the project (Table 1), which includes stakeholders from each of the four (shaded) selection sectors in Figure 6 (*cf.* Collins, 2004).

Table 1: Participating stakeholder organisations/groups by sector

Sector	Participant group (number of participants)
1. Local voices	Elected officials (3) Landowners (1)
2. Expert locals	Residents (13)
3. Expert practitioners	Nottinghamshire County Council (2) Severn Trent Water (2) Environment Agency (2) URS Consultants (1) University of Nottingham (3)
4. Definitive stakeholders	Nottingham Trent University (2) Southwell Flood Forum (6)

Interview transcripts were coded using iterative, in-vivo coding (Given 2008), to develop a shared understanding of the different receptors at risk during the 2013 event, and support the design of the participatory approach and the constituent workshops that formed Stage 2.

5. Participatory model development (Stage 2)

5.1 The participatory modelling approach

To facilitate participatory modelling, the participatory elements of the process (usually a series of workshops) are organised into an overarching structure termed the participatory modelling approach (Voinov and Bousquet, 2010). The approach guides the group from setting objectives and understanding the problem, to working through a series of participatory activities to formalise this understanding into a model, which they can then use to test and evaluate different alternative interventions. Several participatory approaches have been developed (e.g. Vennix, 1996; Barreteau, 2003; Palmer *et al.* 2013), of which this study employed an adaptation of the companion modelling approach (Figure 7). Companion modelling was chosen for its strong emphasis on cyclic model

development which allows a) continuous stepping between the model and field situations; and b) the exploration of possible future scenarios (CIRAD, 2004).

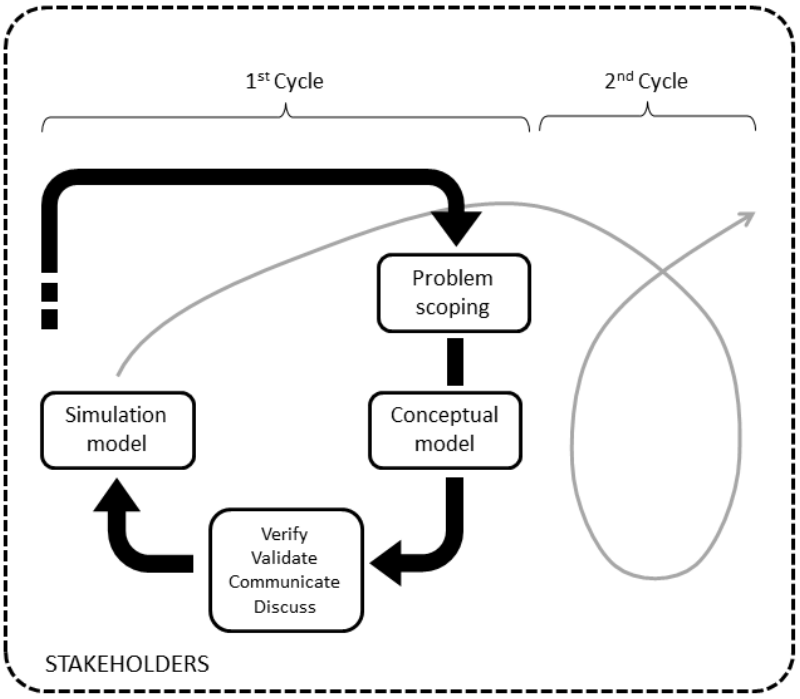


Figure 7: Companion modelling approach (modified after CIRAD, 2004)

5.2 The participatory modelling tool

Participatory modelling tools allow for the formalisation of model variables and the causal relationships that exist between them. To be used in a participatory setting, they must be accessible to a range of stakeholders, including those that have no previous experience of modelling, but be rigorous enough to allow their knowledge to be structured in a way that can be tested, explored and ultimately evaluated. System dynamics provides a suite of tools for representing complex systems, and providing an insight into the dynamic processes that govern their behaviour (Forrester, 1961; Sterman 2001). These processes are guided by feedback, which allows a system to evolve based on its own past behaviour. This ability to model temporal changes and focus on feedback mechanisms sets them apart from alternative tools such as Bayesian networks, which model a snapshot of the system at a given point in time (*cf.* Maskrey *et al.* 2016). Examples of their use in other environmental applications include river basin planning (Palmer, 1994; Palmer *et al.* 1993; 1995; Simonovic *et al.* 1997; Simonovic and Fahmy, 1999); air quality (Stave, 2002); and water resources management (Fletcher, 1998; Stave, 2003; Tidwell *et al.* 2004).

System dynamics has a strong focus on the use of diagrams, which contribute to its accessibility and make it appealing for participatory modelling. Modelling is usually a two-step process, whereby participants sketch abstract causal loop diagrams which they subsequently translate highly into quantified stock and flow diagrams. Causal loop diagrams help participants to describe system structure and expose any assumptions they might have about how it behaves (Wolstenholme, 1999); and consist of a series of variables connected by arcs, which are given a polarity to describe their causal effect. In stock and flow diagrams (Figure 8) these relationships are quantified; with diagrams consisting primarily of two features: stocks (which describe the state of the system at a point in time), and flows (which describe how fast those stocks are rising or falling). Further influencing factors can be represented by variables which either directly or indirectly affect these stocks, or the rate of flow between them.

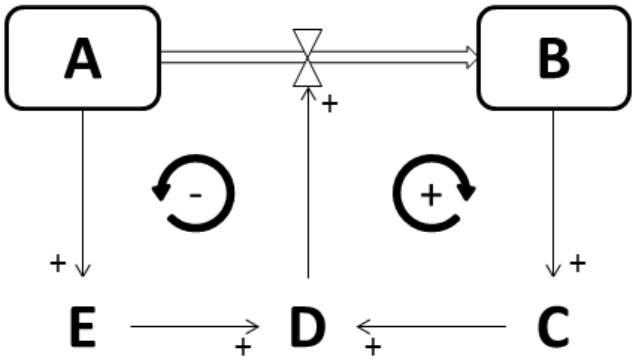


Figure 8: Simple stock and flow diagram

Where these features form a closed loop, they represent feedback, which governs system behaviour. Examples of both a positive (self-reinforcing) feedback loop and a negative (self-correcting) feedback loop are shown in Figure 8. When a simulation is run, model parameters and initial conditions are entered, and the model takes a number of time steps, with system variables updated after each step (Guo *et al.* 2001; Sterman, 2001).

Widely available intuitive software and the aforementioned emphasis on graphical representation, makes the modelling process particularly accessible (Sterman, 2001). Indeed, with only minor facilitator guidance, participants can sketch causal diagrams within the space of a single workshop; and the more complex processes that follow, including sensitivity testing and optimisation, are largely automated (Winz *et al.* 2009). To support the participant group in Southwell, which consisted primarily of local residents with little or no modelling experience, this level of accessibility was considered critical. The focus on exploring system behaviour in response to interventions, rather than making predictions, was useful for encouraging participants to think holistically about the flood risk system; moving away from physical engineered options (which were the focus of hydraulic modelling being conducted elsewhere), to look instead at social interventions enacted by the community. The technical adaptability of system dynamics facilitates this by supporting the use of both quantitative and qualitative variables, interchangeable modules, and adopting elegant methods for dealing with time delays and feedback (Tidwell *et al.* 2004; Winz *et al.* 2009).

5.3 Model development and calibration

The participatory process in Southwell consisted of five evening workshops, each two hours in length. Workshops 1 – 3 constituted the development workshops, in which the problem scope, model variables and model structure were defined. Workshops 4 – 5 constituted the testing and validation workshops, in which participants worked within the model to test different combinations of interventions likely under three future governance scenarios (Figure 9).

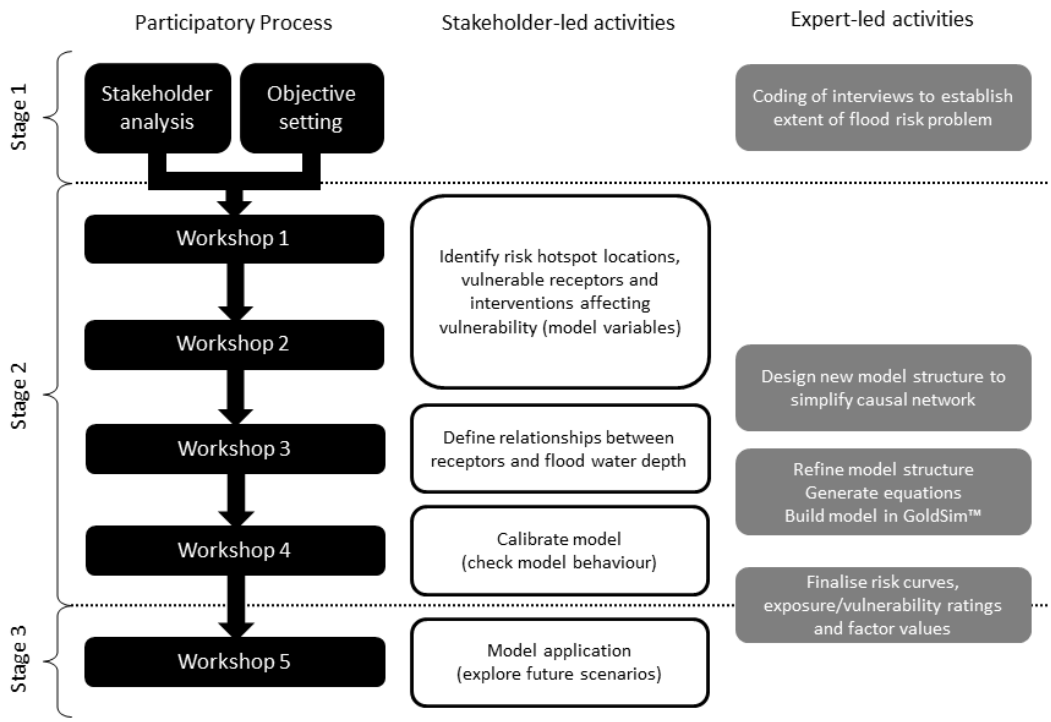


Figure 9: Participatory process adopted in Southwell

In Workshop 1, participants identified eight 'risk hotspots' representing actual locations across the town where high levels of exposure and/or sensitivity in one or more of the receptors resulted in areas of high vulnerability during the July 2013 flood event. Receptors included people (especially groups of sensitive people such as schoolchildren or the elderly), property, cars, roads, emergency access, refuges, and public assets (e.g. electricity sub stations, schools) (Table 2). Participants placed memo holders on a large paper map of the catchment (Figure 10), providing basic information about the characteristics that make each location vulnerable.



Figure 10: Identification of 'risk hotspots' to model the 2013 flood event (above) and GIS mapping revealing how closely the two groups' locations matched (below)

For each location, residents were asked to think about the different receptors present at each location (Table 2), which later became variables in the model.

Table 2: Risk hotspot locations and vulnerable receptors

Location	Property	Residents	Parked cars	Gardens	Driven cars	Pedestrians	Businesses	Access
1. Halloughton Road	X	X	X					
2. Nottingham Road	X	X	X		X			X
3. Church Street	X		X		X	X	X	
4. Potwell Close	X	X						
5. Ropewalk	X	X		X				
6. Archers Field	X	X	X					
7. Merryweather Estate	X	X						
8. Crafts Way	X	X	X					

Following the selection of system dynamics as the preferred methodology, stakeholders were encouraged to organise the eight locations, and the receptors they had identified at each, into a stock and flow diagram in Workshop 2. Although this diagram was not ultimately transformed into a simulation model, it provided a list for potential interventions for each of the eight locations (Table 3). This list of interventions, along with the locations and receptors from Workshop 1, provided the variables for the model.

Table 3: Potential interventions for reducing vulnerability at flood hotspots

Location	Potential interventions	
1. Halloughton Road	Parking awareness	Warnings
	Increase culvert capacity	Property level protection
2. Nottingham Road	Drain clearance	Warnings
	Evacuation plans	Leisure centre alerts
	Emergency plan	Flood wardens
	Road closure	Temporary signage
3. Church Street	Property level protection	Capital changes
	Preparedness	Flood plans
	Road closure	Warnings
	Communications	Slowing cars
	Safety signage	Flood wardens
4. Potwell Close	Property level protection	Flood wardens
5. Ropewalk	Flood proofing	Awareness
	Improved drainage	Property level protection
	Runoff management	
6. Archers Field	(no specific measures discussed)	
7. Merryweather Estate	Runoff management	Floodwater storage
	Improved drainage	Warnings
	Flood wardens	Flood doors
	Road closure	Preparedness
8. Crafts Way	Community level protection	Property level protection

The limited participant knowledge of (and uncertainty in) flow routes in the town, and the lack of available data to quantify the relationships between floodwater levels at different locations, limited the potential to transform the stock and flow diagrams into a working simulation model, which would have been the natural next step in system dynamics. Recognising these limitations, a hybrid model structure was adopted (Figure 11) that refocussed the process on quantifying the vulnerability of different receptors and how this vulnerability changes in response to changing floodwater depths during an event, thus maintaining some temporal aspects of the technique.

In this hybrid model, each of the eight locations is represented by a stock, a component borrowed from system dynamics whose value can change over time in response to changing conditions in its

surrounding variables, and which in this model represented the level of risk at a location. Risk is therefore quantified as a linear scalar unit, defined as a function of water depth and the vulnerability rating of all receptors at the location (see Table 2 and Equation 1). The flood water depths, which provide the temporal aspect of the model, represent flood depth estimates at 15 minute intervals from a hydraulic model of the July 2013 flood event (AECOM, 2015). These data represent the average depth within a 10m circular region centred on an identified datum at each location. As floodwater depths change over time, so too does the level of risk, outputting a risk curve when the model is run.

$$Risk = water\ depth * r_1 * r_2 * r_3 \dots r_n$$

Where r_1, r_2, r_3, and r_n are receptor vulnerability levels ranging from 0-1 and water depth is a modelled estimate of floodwater depth in metres above a set datum at each location.

Equation 1

From Equation 1, we see that the level of risk (and therefore the shape of the risk curve) responds to the vulnerability levels of each receptor. These vulnerability levels will have different relationships with water depth. For example, where properties are situated below the level of the road, they may become vulnerable to flooding as soon as there is any depth of floodwater on the road surface. Conversely, where properties are elevated, it may be cars parked on the roadside that are at greater risk when flood depths are low, with properties only vulnerable when floodwater reaches a higher threshold.

It is these vulnerability levels that individual and community level interventions often seek to manage, thus modelling flood risk as a function of the vulnerability levels of different receptors allows local stakeholders to identify which interventions they perceive to be most effective in reducing vulnerability at different locations.

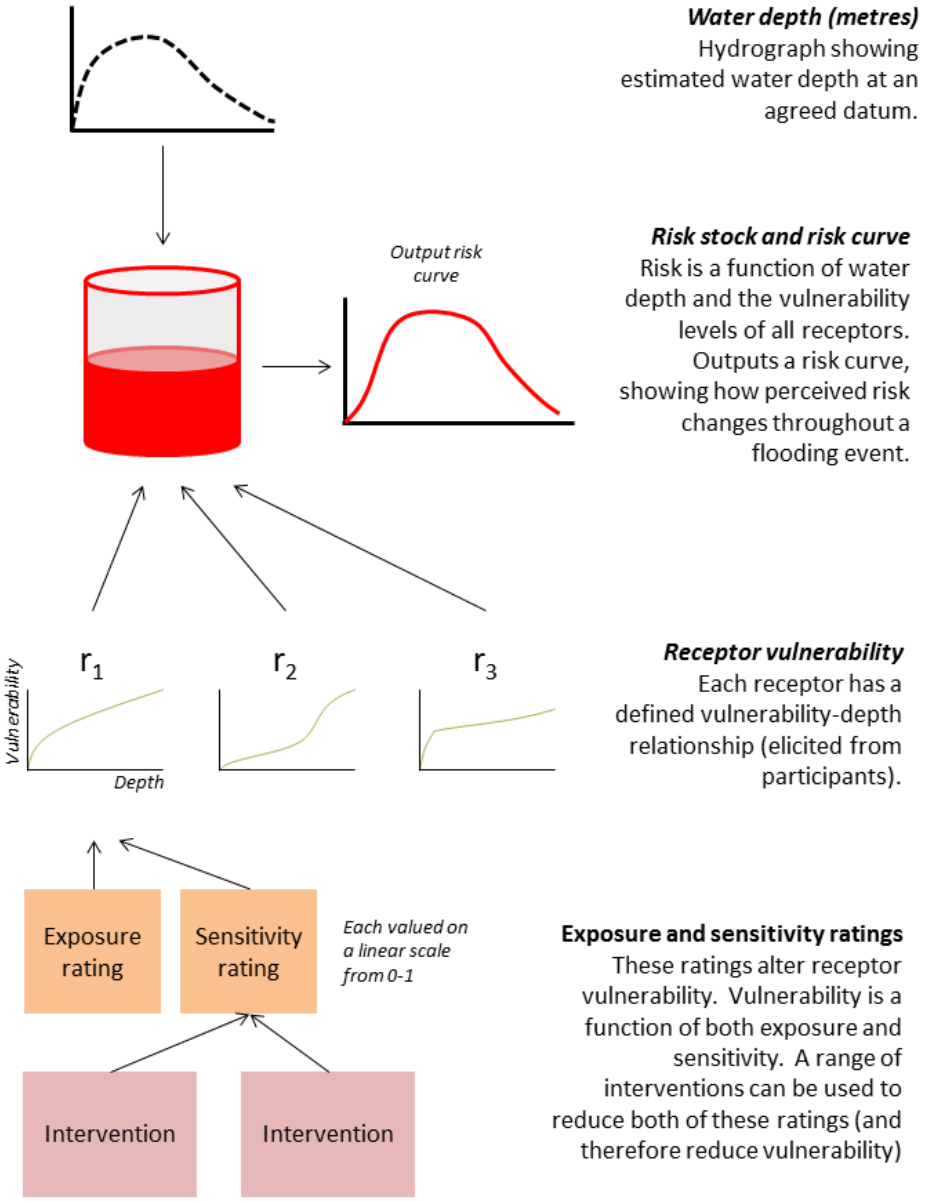
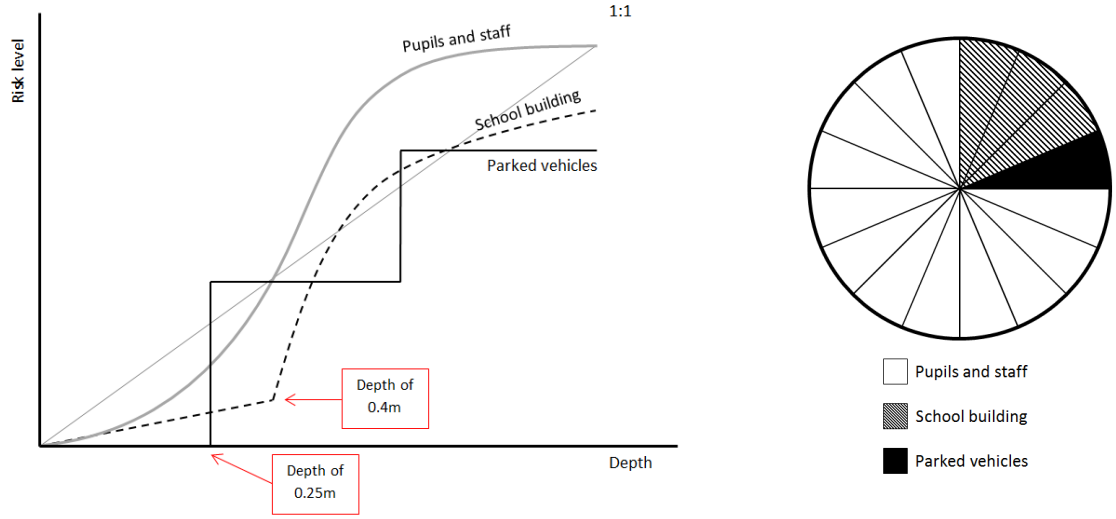


Figure 11: Model structure showing inputs and outputs

In Workshop 3 participants completed a three-step process to quantify the vulnerability levels of all receptors in the model (Figure 12). The focus was on identifying the relationship between vulnerability and floodwater depth for each receptor. Step one involved sketching this relationship and identifying any key thresholds where the nature of the relationship changed (e.g. a step-change, plateau, or rate change in vulnerability) (Figure 12). Step two involved weighting the importance of the receptors present at each location, for which the participants used an empty 16-segment pie chart to graphically apportion vulnerability. Finally, step three involved giving each receptor *a priori* exposure and sensitivity ratings based on their knowledge of the 2013 event. Ratings were given on a linear scale of 0-1 (0 being

no exposure/sensitivity up to 1 being total exposure/sensitivity). Group verification in Workshop 4 helped to ensure that ratings were comparable between locations.

Between Workshops 3 and 4 a second series of model development meetings (n=5) were held with



Receptor 1: Pupils and staff		Receptor 2: School building		Receptor 3: Parked vehicles	
Sensitivity rating (0-1)	Exposure rating (0-1)	Sensitivity rating (0-1)	Exposure rating (0-1)	Sensitivity rating (0-1)	Exposure rating (0-1)
		0.7	0.8		

Figure 12: Example of data elicited from participants in order to define location-specific receptor vulnerability levels

stakeholders to verify the receptor vulnerability information elicited from stakeholders in Workshop 3. These meetings involved site walkovers of the eight locations, choosing a specific datum for each, and discussing how the risk to receptors changed with increasing depth of floodwater. The aim of this activity was to reduce the amount of erroneous model behaviour when the model was presented to participants in Workshop 4, and to give an opportunity for more local stakeholders to have an input into the development of these model inputs.

Following these meetings, a separate model was built for each of the eight locations in GoldSim™ (Version 11.1, GoldSim Technology Group LLC) (Figure 13 and Appendix 6). An equation was developed for each of the receptor vulnerability-depth relationships (Appendix 7), and used to calculate the risk curve (Equation 2), which expresses risk as a function of the vulnerability of all receptors, and their relative weightings (see Figure 12) for each of 405 time steps (one time step = one minute).

$$Risk = (r_1v * r_1w) * (r_2v * r_2w) \dots * (r_nv * r_nw)$$

Where: r_1v = receptor1 vulnerability level corresponding to the water depth at that step (see Equation 3), and r_1w = receptor 1 weighting as a share of total vulnerability at a location.

Equation 2

Receptor vulnerability is a function of water depth, exposure and sensitivity (Equation 3)

$$r_xv = (d * r_xexposure * r_xsensitivity)$$

Where d = effect of water depth on receptor vulnerability, calculated using the depth-vulnerability equations developed in Workshop 3 (see Appendix 7 for a table of all depth-vulnerability equations), $r_x$exposure = the level of exposure of receptor x, and $r_x$sensitivity = the level of sensitivity of receptor x.

Equation 3

Exposure and sensitivity can be affected by enacting different interventions (Equation 4). Each of these interventions has an effectiveness score ascribed to it, which varies from 0 (reduces exposure/sensitivity to zero) to 1 (has no effect on reducing exposure/sensitivity). Some interventions affect several receptors, while others affect the exposure or sensitivity of a single receptor. For example, we see in Figure 13, that the exposure of residents (r_1) can be affected by changes in three interventions: runoff, flood storage and drainage.

$$r_xexposure\ and\ r_xsensitivity = baseline * intervention_1 * intervention_2 * \dots intervention_n$$

Where baseline = a value assigned to each receptor to represent the existing levels of exposure and sensitivity (i.e. before any interventions are implemented).

Equation 4

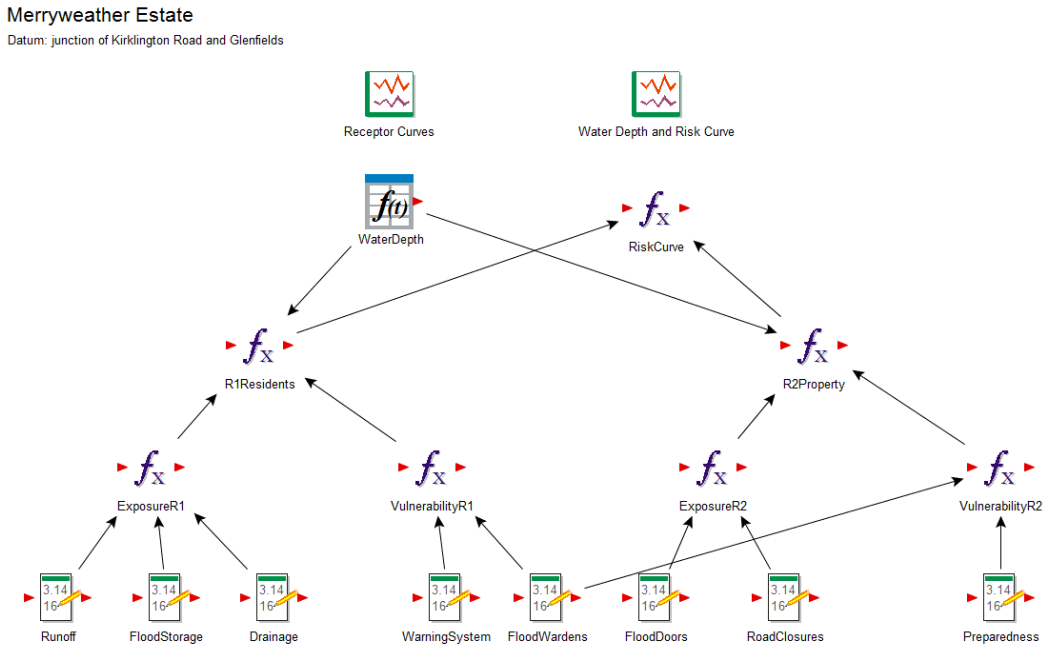


Figure 13: Example model for one of the eight risk hotspot locations

(for full set of model diagrams see Appendix 6)

Before using the model to explore flood risk management options in Southwell the participants completed a model calibration activity in Workshop 4, which involved presenting the Goldsim models to the participants and working through a number of simple tasks with them, to both familiarise them with the software and explore how the model behaved when inputs were altered. The aim of this activity was to check that the model behaviour conformed to participants' hypothetical expectations; enabling erroneous model behaviours to be traced and, where necessary, rectified by adjusting receptor depth-vulnerability relationships, and/or exposure and sensitivity ratings. Between Workshops 4 and 5, University of Nottingham researchers adjusted the receptor vulnerability-depth equations (see Appendix 7) and made further refinements to the model in response to comments made by participants in Workshop 4.

6. Using the model to explore interventions and their effect on risk (Stage 3)

In order to evaluate combinations of interventions (Table 3) in a way that was meaningful to participants, a scenario analysis approach was taken. Participants identified three future management scenarios they wished to explore using the model (Table 4), each encompassing a range of interventions that could be enacted and managed on a community scale. Some of the interventions proposed under these scenarios are already being implemented in Southwell, while others await funding or are in the early planning stages.

Table 4: Scenarios used to explore the effect of different interventions on flood risk

Scenario	Description
Baseline	This scenario provides an indication of the current situation in Southwell. Given several months have passed since the July 2013 event; many of the identified interventions are being implemented. This scenario aims to capture these post-event changes.
Community stewardship	This scenario involves the community taking responsibility over guiding flood risk reduction in their local area, with the help of local government advice and subsidy. Under this scenario, interventions are often low-cost, small-scale changes that aim to promote the natural functioning of the environment. In Southwell, this includes the seasonal clearing of the Potwell Dyke and other watercourses (as well as drain intakes and ditches in some cases) of natural and anthropogenic debris.
Personal enterprise	This scenario involves actions taken by individuals to protect their own property, vehicles and family members, with the help of government advice and subsidy. Under this scenario, people evaluate their own flood risk and retain the autonomy to make decisions. In Southwell, this scenario includes the adoption of property level protection measures, as well as the flood-proofing of homes to reduce both exposure and vulnerability to flooding.
Innovative governance	This scenario involves community-wide flood risk management by several individuals and organisations. Under this scenario the community are involved in appraising options for reducing flood risk, and often take a role in their implementation. In Southwell, this scenario includes the road closure scheme currently being developed by Southwell Flood Forum. The scheme, one of the largest of its kind in Europe, involves 20 road closure points initiated by community members trained to act as 'road closure wardens' in a flood event.

In Workshop 5, participants were asked to select up to ten interventions (across all risk hotspot locations) that they felt were most likely to be implemented under each scenario. Working in small groups, they were then asked to estimate how effective they perceived the intervention would be in reducing exposure and/or sensitivity of receptors at a location, on a scale of 0 (exposure/sensitivity reduced to zero) to 1 (no effect on exposure/sensitivity). Each smaller group then reported back to the group as a whole, and the choices of interventions and their individual effects were ratified. Following the workshop, these scores were used as prior values (see Figure 12) for the baseline model run (see Equation 4 and Table 4).

The outputs from each model (i.e. each hotspot location) consist of an overall risk curve for each scenario (overlying water depth), and a series of individual risk curves for each receptor present at that location (Figure 14). These curves show how risk is perceived to change over the course of a flooding event, as a result of both water depth at a location, and the combined vulnerability levels of the receptors at risk. A full set of model outputs is provided in Appendix 8.

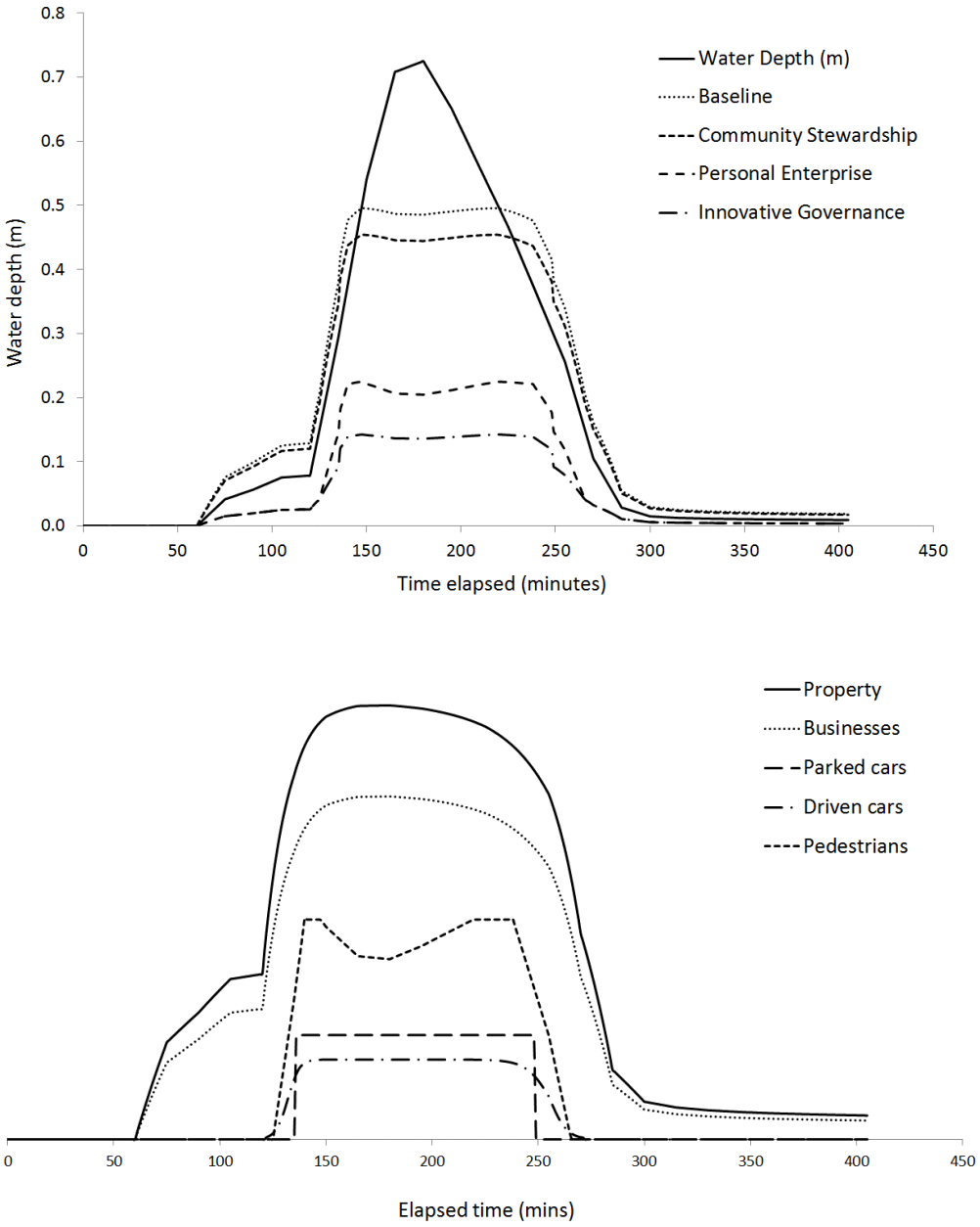


Figure 14: Example of scenario analysis (above) and individual receptor curves under the baseline scenario (below)

The example in Figure 14 shows the risk curve created for each scenario in Church Street, one of the eight risk hotspots identified in Workshop 1. The water depth curve shows how the estimated water depth at Church Street changed over the course of the 23rd July 2013 event (as modelled by AECOM, 2015). Exploring the risk curves for each scenario showed that while vulnerability is reduced under each of the three scenarios, participants perceived that the interventions most likely under the personal enterprise and innovative governance scenarios (Table 2) are those that offer the greatest reduction in vulnerability.

The shape of the curves for the baseline and all three management scenarios is similar, showing a plateauing of risk at a water depth of 0.5m. A closer investigation of the receptor curves that make up the baseline risk curve (lower section of Figure 14), reveals which receptors stakeholders perceive to be vulnerable at different depths. It shows, for example, that even at relatively low depths of flood water (below 10cm) properties and businesses at the location are perceived to be vulnerable. In contrast, parked and driven vehicles are perceived to become vulnerable at much greater depths, and may be resilient to smaller 'nuisance flooding' events.

The potential of different interventions to reduce vulnerability at Church Street (Figure 15) reveals further insights into participant perceptions of risk, and the belief they place in their ability to employ different interventions at a particular location. It shows how effective participants perceive each intervention could be (note that if the perceived vulnerability remains at 1 then it can be assumed that the intervention was deemed unlikely under that scenario). It is only when these individual scores are examined that we can attribute the effectiveness of personal enterprise and innovative governance to the promotion and perceived potential of property level protection as a likely intervention under both scenarios. We also find that some interventions are not perceived as likely under any scenario, possibly suggesting that they are either not feasible at the location (e.g. flood plan) or participants felt they were outside of the community's ability to effect (e.g. capital changes, turbidity).

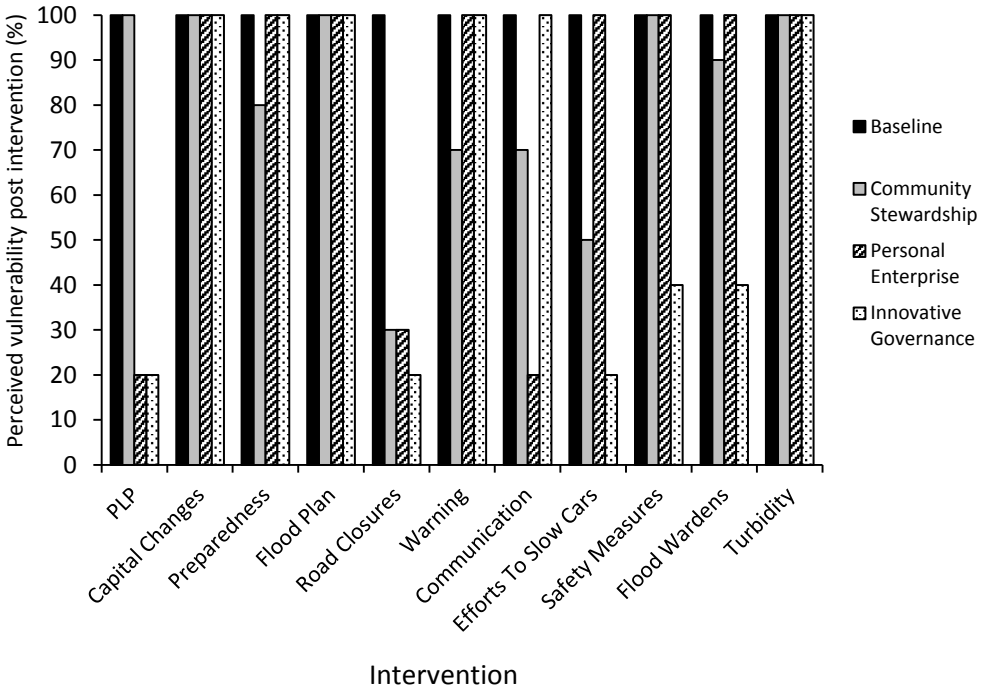


Figure 15: Perceived vulnerability reduction as a result of the interventions deemed likely under different future management scenarios at Church Street

Although for the sake of brevity only one of the eight locations is examined here, similar detailed insights can be drawn at each location (see Appendix 8 for outputs from all modelled locations), building a community-wide picture of risk perception, and the belief that stakeholder place in different interventions. Practitioners can utilise these insights to assess local stakeholders' understanding of vulnerability and exposure; evaluate their levels of threat and coping appraisal (see Figure 2); and identify the interventions that have the greatest levels of public support. In addition, they could input estimated water depths from flood events of different return periods, to see how perceived risks change in response to different frequency events.

7. Evaluation

The approach used to evaluate the participatory modelling process adopts a framework derived by fusing the work of Beierle (1999) and Webler and Tuler (2002), studies which both emphasise the importance of evaluating the process alongside its outcomes (Figure 17). Outcomes are further split into substantive outcomes (e.g. assessment and appraisal of interventions for mitigating risk) and longer-term social outcomes (e.g. building of social capacities).

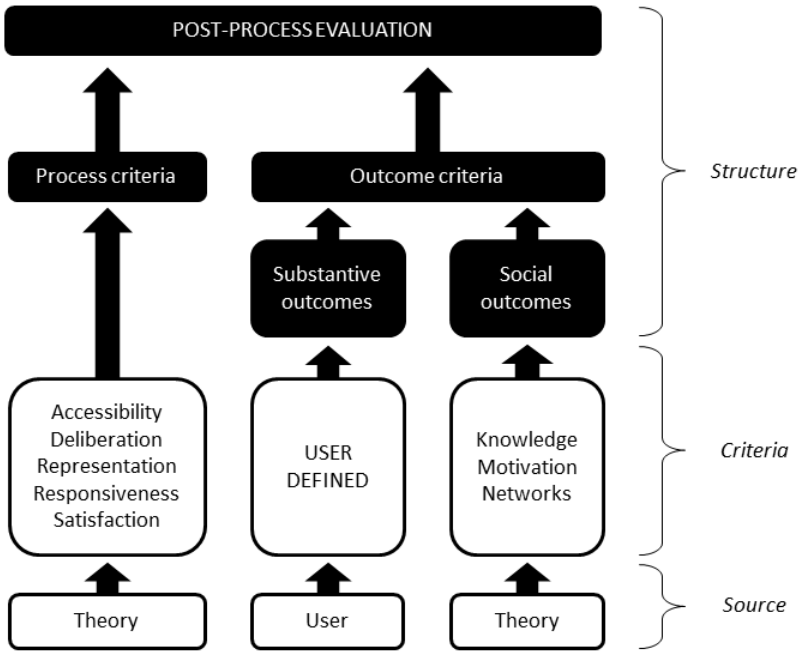


Figure 17: The framework used to evaluate the participatory modelling process in Southwell showing the sources of evidence from which criteria were developed

7.1 Process evaluation

Process criteria assess the efficacy of the organisation, activities and tools used to deliver active and inclusive participation; and were developed from an exploration of the normative and pragmatic claims made for participation (*cf.* Fiorino, 1990; Beierle and Konisky, 2000; Halvorsen, 2001; Butterfoss, 2006). Five individual criteria were devised following a literature review of >30 papers employing participatory approaches in the environmental sciences (Table 3). Accessibility and representation criteria are derived from normative claims that participation can facilitate direct involvement of local stakeholders, and foster trust in, the decision-making process. Responsiveness, satisfaction and deliberation criteria are derived from pragmatic claims that participation can better meet local need and priorities; develop ownership and lasting support for interventions; and widen the knowledge base that informs local flood risk management.

Table 3: Criteria and findings from process evaluation

*Note: participant score provides an indication to whether participants believed that the criteria were achieved. The value presented is an average of all participant responses, given on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Criteria	References	Participant score*	Key Findings
ACCESSIBILITY 1. Participatory activities, resources and language were designed such that all participants could fully engage, regardless of skills and experience. 2. Clear and frequent communication kept the modelling process transparent.	Godschalk and Stiftel (1981); Rowe and Frewer (2000); Abelson *et al.* (2003); Hare *et al.* (2003); Prell *et al*. (2007); Ramsey (2009)	4.34	• Language of system dynamics uses jargon which requires clear explanation when it is introduced • Attending more workshops built up clearer understanding • Between-workshop communications were effective, especially where workshops were missed • Process became clearer as time progressed
DELIBERATION 3. The participatory process fostered knowledge exchange, debate and consensus building.	Susskind and Cruikshank (1987); Kemmis (1990); Dryzek (1997); Hartig *et al.* (1998); Smith and Wales (1999; 2000); Beierle and Konisky (2000); Halvorsen (2001); Abelson *et al.* (2003)	4.46	• Small group working enjoyed, but meant participants were not involved in all aspects • Holistic approach made participants think about the wider picture in managing flood risk • Quality of inputs into model depended on who attended

REPRESENTATION 4. The participants are representative of the affected community and the full range of views. 5. All participants were given opportunity to make a substantive contribution.	Crosby (1995); Phillips (1995); Webler (1995); Hartig *et al.* (1998); Beierle (1999); Smith and Wales (1999; 2000); Halvorsen (2001); Abelson *et al.* (2003); Butterfoss (2006)	4.20	• Representation from across the community brought different experiences to the process • Not all participants were directly affected • Greater input from practitioners could improve process • It felt a safe place to make a contribution
RESPONSIVENESS 6. Participatory tools were chosen according to local objectives, resources and available data. 7. The participatory process was flexible to change, with the agenda and activities shaped by the needs and goals of the participants.	Fiorino (1990); Webler (1995); Beierle and Konisky (2000); Prell *et al.* (2007); Voinov and Gaddis (2008); Ramsey (2009); Voinov and Bousquet (2010)	3.93	• Process was sufficiently flexible while being structured • Flexibility tended to be across the process rather than in individual workshops • Methodology flexible to allow breadth of context-specific information and experiences to be input • Methodology lacked objectivity at times
SATISFACTION 8. Participatory activities were facilitated in a professional and effective manner. 9. The participants knew what was expected of them and what they could expect to gain from participating. 10. The process had clear purpose, objectives and direction.	Rogers *et al.* (1993); Hartig *et al.* (1994); Butterfoss *et al.* (1996); Beierle (1999); Chess and Purcell (1999); Kenney *et al.* (2000); Halvorsen (2001); Butterfoss (2006)	4.39	• Expectations became clearer as time went on • Expectations of what participants could gain from participating was unclear at the outset • In-workshop support helped with understanding • Some unclear about what the tangible outcomes will be • Timing is important - process was to some extent overshadowed by release of numerical flood model

Criteria 1 and 2 describe the overall accessibility of the participatory elements of the process (workshops, resources, language) as well as any communications with residents between workshops. Responses showed participants found the language of system dynamics complicated at the outset of the process, and stressed the importance that an opening workshop should go 'back to basics' to establish a broad understanding of the technique (Criterion 1). Participants agreed that accessibility and understanding increased with the number of workshops attended, and were further enhanced through clear between-workshop communications, especially where participants chose to attend infrequently (Criterion 2).

Criterion 3 assesses how deliberative the process was, in particular whether it fostered knowledge exchange and debate. Participants reflected that the process encouraged knowledge transfer through small group working and the involvement of participants from across the community. Concerns were voiced that model quality was limited by the breadth of participant knowledge available at each workshop.

Criteria 4 and 5 ask whether the group was reflective of the affected population in Southwell, and if individuals felt they were given the opportunity to put forward their views. Generally, the participant group was deemed representative of the community, although some groups (notably more vulnerable groups such as the elderly) were not present, and agency involvement was limited (Criterion 4). Those participating felt that the process provided a safe space in which to speak and contribute to model development (Criterion 5).

Criteria 6 and 7 evaluate whether participants felt the process was sufficiently flexible to meet the goals and needs of the group, and to adapt to the local context. Participants praised the method for bringing a breadth of different knowledge sources together (Criterion 6). Responses showed that while the process as a whole was flexible, individual workshops followed a stricter agenda (Criterion 7).

Finally, criteria 8, 9 and 10 explore how satisfied participants were with the process, in order to give an overall assessment of its quality. Respondents were impressed with the facilitation of the process and participatory activities from the outset (Criteria 8), while expectations of participants and their level of understanding became clearer as time went on and were positively correlated with workshop attendance (Criteria 9). Expectations of what participants could expect to gain from participating were less clear, and while some were satisfied that discussion and knowledge sharing were outcomes in themselves, others sought concrete tangible outcomes that the method could not deliver (Criteria 9 and 10).

7.2 Substantive outcomes evaluation

Substantive outcome evaluation assesses the extent to which the participatory process facilitated the appraisal of individual and community-scale interventions, and their capacity to increase community resilience through the reduction of receptor vulnerability and exposure. Six criteria were developed from iterative, *in vivo* coding (Given, 2008) of transcripts of semi-structured interviews (n=2) with core staff at Southwell Flood Forum, and are provided along with key findings in Table 4.

Table 4: Substantive outcome evaluation

Criteria	Specific goals
1. Understanding public perception of risk	• Hearing about others' perceptions of risk • Increasing discussions about risk within community groups
2. Exchanging knowledge	• Getting the full range of community views • Fostering greater agency (government and regulatory) involvement*
3. Understanding the roles of different agencies	• Developing trust within the community • Developing trust in the Lead Local Flood Authority and the Environment Agency*
4. Strengthening key messages	• Fostering a sense of responsibility • Creating a forum for structured and focussed discussion
5. Identifying intervention options	• Thinking about risk in a holistic and structured way • Highlighting all possible options • Focussing discussion on interventions believed to offer the greatest impact
6. Increasing public participation	• Creating opportunity for those less articulate or confident to participate • Getting people outside of the 'core group' to participate • Getting ideas from a wider range of people

Where user goals centred on public participation and knowledge transfer, representatives of Southwell Flood Forum felt that these were achieved by the creation of a forum in which public could be involved in a structured process of sharing their knowledge and experiences, and engaging in deliberative discussion. However, goals associated with developing understanding, networks and trust with external flood risk management agencies (marked with an asterisk in Table 4) would have required greater representation from those agencies in order to be achieved.

7.3 Social outcomes evaluation

Social outcome evaluation criteria (Table 5) assess the extent to which the participatory process helped to set a mandate for longer-term social changes and improvements to community resilience, through an increased understanding of community inventions and their potential to reduce the vulnerability and exposure of local receptors (*cf*. Cutter *et al.* 2008). These were derived from >15 studies exploring the relationships between three components of social capacity: knowledge exchange, motivation to proactively reduce flood risk, and networking between stakeholders (Buchecker *et al.* 2013). The capacities provide indicators that a community is able (and likely) to build and maintain flood risk resilience (Kuhlicke *et al.* 2011).

Table 5: Criteria and findings from social outcomes evaluation

*Note: participant score provides an indication to whether participants believed that the criteria were achieved. The value presented is an average of all participant responses, given on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Criteria	References	Participant score*	Key findings
KNOWLEDGE CAPACITY 1. Participants shared in the coproduction of knowledge on local flood risks (including hazard, exposure and vulnerability). 2. Participants discussed their perceptions of risk, and explored a range of interventions that could mitigate them. 3. Participants know who to go to for support within and outside of the community, and feel better prepared for another flood event.	Folke *et al.* (2005); Howgate and Kenyon (2009); Nobert *et al.* (2010); Höppner *et al.* (2012); Buchecker *et al.* (2013).	4.21	• Process helped residents feel 'better equipped and more knowledgeable'. • Provided an opportunity to talk about actual experiences and perceptions of risk. • Process helped to focus attention on the key issues/ interventions.
MOTIVATION CAPACITY 4. Participants feel motivated to take ownership of, and responsibility for, a proactive role in the reduction of local flood risk. 5. Participants identified a range of appropriate interventions that could be implemented by either individuals and/or the community.	De Long and Fahey (2000); Uphoff (2000); O'Neill (2004); Deeming (2008); Buchecker *et al.* (2013)	3.98	• Process helped to support levels of motivation that were already high in the community. • Process helped to get new people engaged with flood risk issues.
NETWORK CAPACITY 6. Relationships were developed between participants and organisations both within and outside of the local flood risk community. 7. Trust was improved between participants from both within and outside of the local flood risk community.	Putnam (1993; 2000); Pelling (1998; 2003); Ardichvili *et al.* (2003); Folke *et al.* (2003); Chazdon and Lott (2010); Buchecker *et al.* (2013)	3.65	• Process developed trust within the group, but not particularly with outside agencies. • Useful for residents to get to know those involved with the work of the Flood Forum.

Criteria 1, 2 and 3 assess knowledge capacity, which evaluates local knowledge on flood risk: how well it is organised, and the extent to which it can be used to effectively prepare for, manage, recover from, and become more resilient to, flood events (Folke *et al.* 2005). Respondents commented on the production of new knowledge, through discussion on different mitigation strategies and the spatial variability of risk; and valued the opportunity to share their personal experiences of flooding and structure these into a conceptual model (Criteria 1 and 2). Although participants already felt they knew who to go to for support within the community, they felt it was helpful to meet with other affected residents (Criterion 3).

Criteria 4 and 5 evaluate motivation capacity: the extent to which members of the community are engaging with activities and initiatives designed to reduce flood risk (O'Neill, 2004). These criteria align particularly strongly with the goals of Southwell Flood Forum (see Section 7.2). Most residents felt that levels of community motivation were already high, although the process did attract a number of participants who hadn't previously engaged with community activities (Criterion 4). Some respondents felt that intervention identification could have been more central to the study (Criterion 5).

Criteria 6 and 7 relate to network capacity, which refers to the ties between individuals and groups, both within and outside of the local community, that facilitate the effective sharing of information, resources and expertise (Putnam, 2000). Although some organisations, notably Nottingham Trent University (a major local landowner), reported new relationships resulting from the process; limited involvement from the Lead Local Flood Authority and Environment Agency affected the establishment of ties with those organisations (Criterion 6). Within the community, responses unanimously agreed that the process had promoted the development of trust, while recognising that many Southwell residents were already highly engaged with local flood risk management through the work of the Forum (Criterion 7).

8. Lessons for local flood risk management

Despite the sharing of responsibilities for flood risk management among a wider range of actors at the local level, and an assumption that in the cases of ordinary watercourses and surface water flooding, these responsibilities extend to assessing risk and developing interventions to mitigate it, there remains a lack of active participation in local flood risk management. Where participation is present, it often consists of consultation periods located at critical junctures in the decision-making process, rather than more active participation that involves local stakeholders throughout. While the theoretical arguments for participation are well understood, the practicalities of how to involve local stakeholders in flood risk management remain unclear, especially where flood risk management largely relies on evidence from

hydrologic and hydraulic models – an area whose accessibility traditionally requires specialist technical expertise and knowledge.

The participatory process outlined in this paper shows how aspects of system dynamics can be used to support participatory modelling, an approach utilising low-complexity techniques to elicit and structure local knowledge. While the conceptual models produced using these techniques will never replace traditional flood risk modelling, they can be complementary, capturing local perceptions of risk and allowing local stakeholders to explore intervention options in ways that consultation alone cannot facilitate. In this paper, local residents and members of a local flood action group co-produced a conceptual model of flood risk to allow them to review the effectiveness of different interventions (some of which they were already trialling), to reduce flood risk at critical locations throughout the community. While concurrent numerical modelling was tackling the sources and pathways of flooding, the community were able to assess their own set of softer interventions that deal almost exclusively with reducing vulnerability of different receptors by influencing their exposure and/or sensitivity. Micro-managing vulnerability at the local level requires methods that can harness the wealth of tacit and experiential knowledge that exists across the community.

From a methodological standpoint, the study reveals the potential for using elements of system dynamics in a participatory setting, to model the probable effects of a wide range of interventions, drawing on public perception of risk. It achieves this by allowing stakeholders to bring to the table their own experiences of past flooding events, and use this knowledge to explain to others how different receptors are placed at risk during events of different frequencies. Specifically, the temporal aspects of system dynamics, which in this example facilitated stakeholders in exploring how vulnerability changed as a result of the changing depth of floodwater, allowed them to explore how different interventions might be more or less effective at different locations. This exploration highlighted how evidence on those interventions already in place, sourced from members of the local community, could be used to assess their efficiency and highlight which are worth pursuing on a larger scale and/or in other locations.

In addition to the benefits of the method itself, the strengths of taking a more active participatory approach included the bringing together of disparate pockets of knowledge from across the community, in order that those organisations tasked with managing local response, have a fuller, more holistic picture of flood risk that enables them to better focus their limited resources to bring about the greatest improvements in community resilience. As many interventions are organised by individuals or the community, evidence on their effectiveness only exists within the local stakeholders involved with their planning, management and implementation.

Applying system dynamics to flood risk management in a participatory setting revealed several challenges. While system dynamics is well-established as a modelling technique, some elements were not fully grasped by the participant group in Southwell, whose limited technical capacity and experience resulted in adaptation and simplification of the technique, such that the process could remain accessible and meaningful. This simplification resulted in a hybrid model, which sacrificed some of the celebrated features of system dynamics, notably using feedback loops to describe the system structure, in favour of a linear cause-effect structure that used a limited set of the techniques' modelling capabilities. Furthermore, a lack of evidence to quantify the movement of risk and flood water from location to location resulted in a series of isolated individual models to represent each location. Despite these simplifications and modifications, the process enabled the community to complete a holistic assessment of their current and planned intervention strategies, by collecting and structuring local knowledge on the vulnerability and exposure of affected receptors across the community. It highlighted the locations in which each intervention was most effective at reducing risk, along with those where an alternative approach might be worthwhile exploring.

In conclusion, system dynamics provides a tool that is valuable for bringing stakeholders together to discuss flood risk, and explore potential interventions that build resilience. It has particular potential for using local knowledge to facilitate the allocation of limited community resources, to achieve the greatest reductions in vulnerability. The reliance on participants' perceptions of risk to calibrate the model (Section 5.3) limit the scope to use system dynamics (as presented in this paper) for options appraisal and identification, particularly for options operating on the community and/or catchment scale. Its strengths lie in supporting a review of community risk response (see Figure 1), specifically where those responses are organised by individuals and local interest groups, and focus on building flood risk resilience. This complements ongoing hydrologic and hydraulic modelling by providing detailed information on the spatial distribution of local stakeholder risk perceptions.

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IV) Paper IV.

Towards evaluation criteria in participatory flood risk management

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Abstract

Flood risk consists of complex and dynamic problems, whose management calls for innovative ways of engaging with a wide range of local stakeholders, many of whom lack the technical expertise to engage with traditional flood risk management practices. Participatory techniques offer potential for involving these stakeholders in decision-making, yet limited advice is available to users in choosing which techniques to employ and what they might expect them to deliver. Assessing the effectiveness of participatory approaches in local flood risk management is a critical step towards better understanding the building of community resilience. This paper presents a framework for evaluating participatory approaches to flood risk management that covers four evaluation elements (context, process, substantive and social outcomes). Practical success criteria are provided for users, with references indicating where further advice and guidance can be sought. Criteria are tailored to the requirements of flood risk management, and aim to be sufficiently flexible for the framework to be easily transferable.

Highlights

- Proposed holistic evaluation of participatory process, outcomes and context
- Practical success criteria derived from literature review
- Criteria supported by flood risk management examples
- Social outcome evaluation emphasises the building of social capacity
- Social capacity argued as prerequisite for enhancement of community resilience

Keywords

Evaluation, participation, flood risk management, social capacity, community resilience

1. Introduction

Shifts in the governance of flood risk in England, from state-centred management towards a 'greater reliance on horizontal, hybrid and associated forms of government' (Hill and Lynn, 2005: 173) have paralleled an increased emphasis on stakeholder participation. Following a review into the 2007 floods in the UK (Pitt, 2008) several policy changes were introduced by the Flood and Water Management Act (2010) including: a) the devolvement of responsibilities to local authorities (in a new role as Lead Local Flood Authorities), who are tasked with developing flood risk management strategy at the local level and maintaining a flood asset register (Twigger-Ross *et al.* 2014); and b) a new partnership funding approach introduced in 2011 (DEFRA, 2011). However, certain aspects of decision-making, including the allocation of grant-in-aid and partnership funding finance, and spatial planning guidance, were not devolved, thus maintaining critical modalities of power and control within central government (Penning-Rowsell and Johnson, 2015).

The idea of public participation has gained prominence in flood risk management since it has been recognised that pure structural engineering interventions and short-term response strategies to crises are not satisfactory (*cf*. European Commission, 2007). Therefore, attention is increasingly being given to long-term and non-structural mitigation strategies including a wide range of management interventions involving the public. This increased involvement of citizens in risk management efforts has a positive impact on both risk awareness and disaster preparedness; second, the local population may provide knowledge that is fruitful for risk prevention efforts; third, the involvement of the public legitimises processes and enhances the acceptance of prevention measures; and, finally, the coping and adaptive capacity of the different actors involved at the local level will be strengthened (Bulkeley and Mol, 2003; Nye *et al.* 2011).

Previous UK studies on stakeholder involvement in local flood risk management (Table 1) merge on two key challenges:

(i) The COLLABORATION CHALLENGE:

flood risk management should be conducted locally and be developed in collaboration with local stakeholders, where those at risk become active participants in risk governance; and

(ii) The CAPACITY-BUILDING CHALLENGE:

capacity must be built at the local level, acknowledging new sources of knowledge and expertise, particularly with regard to non-structural responses, the management of surface water, flood recovery and insurance.

Table 1: Selected UK studies involving stakeholders in local flood risk management

Challenge	Example	Brief description	Reference/s
Collaboration	Ryedale, North Yorkshire, England	Experiment in knowledge co-production between local people and academics, building public capacity to intervene and generate solutions with widespread public support.	Ryedale Flood Research Group (2008); Lane *et al.* (2011); Landström *et al.* (2011)
	Yorkshire Region, England	Exploration of Learning and Action Alliances (LAAs) as a means of managing complex problems through stakeholder deliberation and the mutual development of ideas.	Ashley *et al.* (2012)
	Cranbrook, NE London, England	Study into the potential for collaborative modelling to support active involvement of stakeholders, communication of flood risk, and promotion of social learning.	Evers *et al.* (2012)
Capacity-building	Bradford, England & Glasgow, Scotland	Investigation into individual and institutional response to flooding events, with a particular focus on managing flood risk by enhancing the social factors related to resilience.	Cashman (2009; 2011)
	Gloucester, England	Exploring how local knowledges were collated, shared, and utilised to build local resilience; using stakeholder interviews taken before and after the summer 2007 floods.	McEwen and Jones (2012)

Although participatory approaches are often viewed as more legitimate, democratic and inclusive, several studies have warned against taking this romanticised view (*cf.* Haughton *et al.* 2015). The need remains to understand the trade-offs between the considerable resource requirements that participation may necessitate and the potential benefits of participatory approaches. Many studies report on the benefits of participation from a normative perspective, while their actual gains (from a substantive and instrumental perspective) may be those most valuable to flood risk management. This implies a need for holistic evaluation of participatory processes and their outcomes.

This paper engages with theoretical literature to present an evaluation framework for participation in flood risk management. Traditionally flood risk management is a field which employs complex techniques to model and understand the spatial distribution of risk. To contribute to local flood risk management, participatory approaches need to employ techniques which are accessible to stakeholders with limited or no technical expertise, while remaining sufficiently robust to capture complexity. Many of the participatory modelling techniques arguably best suited to this task (e.g. Bayesian networks, system dynamics, fuzzy cognitive mapping) have yet to be widely applied in flood risk management. A flexible evaluation framework will support users in selecting the most appropriate technique for a given context.

The objectives of this paper are twofold:

(i) to outline a framework for evaluating participation in flood risk management by exploring the dimensions and determinants of *effectiveness*; and

(ii) to populate that framework with practical criteria that allow users to design and undertake *effective* participation in a range of different contexts.

The framework proposes an evaluation of four connected elements (Figure 1).

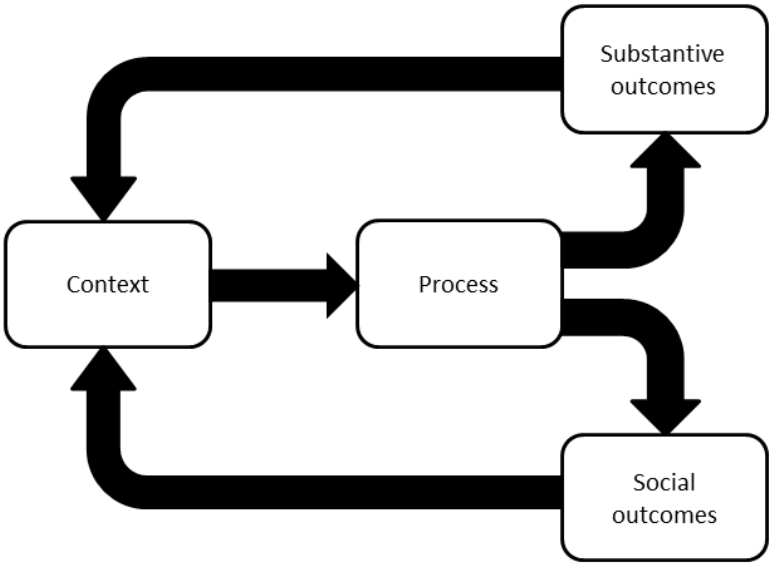


Figure 1: Evaluation elements

Process criteria, while insufficient in isolation, are essential for ongoing improvement of participatory processes and providing feedback to facilitators. The aim here is not to argue that there is an ideal participatory process that one should aspire to, but instead to assess characteristics that are common

to all participatory processes, that collectively affect the efficacy of a process to achieve the collaboration and capacity-building challenges identified earlier. Appreciating that effective flood risk management needs to be tailored to local needs and priorities, an evaluation of context is made prior to participation. Context criteria thus provide a pre-assessment of an area's predisposition to participation, guiding technique selection and implementation, such that acceptance and engagement probabilities are maximised. Substantive outcome criteria assess a process against its ability to achieve users' objectives and expectations, which are identified during context evaluation before a process and assessed in collaboration with users immediately after. Finally, social outcome criteria assess the ability of a process to enhance community flood resilience. As many social effects are delayed in time, this is achieved by exploring aspects of the participatory process that directly promote three constituent social capacities: knowledge exchange, motivation to proactively reduce flood risk and networking between stakeholders (Buchecker *et al.* 2013). Taken in combination these capacities interact to determine the way in which a community can prepare for, resist the impact of, respond to, and recover from a flood event, in other words, indicating their level of community resilience. They primarily assess the extent to which the participatory process is addressing the capacity-building challenge.

Throughout this paper, the word *participant* refers to all persons taking part in the participatory process; the word *facilitator* refers to those delivering the participatory activities; and the word *user* refers to those that will use the outcomes of the process (i.e. those driving the process and undertaking the evaluation), who may or may not also be participants. In some cases the user may be a single easily identified organisation (e.g. the Environment Agency) and in others there may be multiple users who are interested in different outcomes.

2. Evaluating the effectiveness of participatory processes

While early attention was given to the benefits of participation and conceptual frameworks for public involvement (Chambers, 1994; Pretty, 1995); recent research has shifted focus to the designing of more effective, legitimate participatory processes with a strong emphasis on evaluation (Rowe and Frewer, 2000; Abelson *et al.* 2003).

2.1 Dimensions of effectiveness

Understanding the effectiveness of participation is of great interest to users, especially with regard to building community flood resilience. Young (1994) identifies six dimensions to explain variations in the effectiveness of environmental governance systems. In this paper, we draw on four of these dimensions to frame our evaluation framework for participation in flood risk management:

(i) Effectiveness as problem solving

(ii) Effectiveness as goal attainment

(iii) Behavioural effectiveness

(iv) Constitutive effectiveness

The first dimension, *effectiveness as problem solving*, concerns the extent to which processes solve the problems that motivated them to be created in the first place. The second dimension, *effectiveness as goal attainment*, measures the extent to which users goals are achieved over time. In each process, user goals will vary according to local needs and priorities, and this dimension does not assume that by meeting all user goals, the broader challenges of participation in flood risk management (Section 1) will be addressed. Both of these dimensions map onto the substantive outcomes evaluation element of this framework (Figure 2), where the aim is to assess the extent to which the process has achieved user goals. These dimensions address the COLLABORATION CHALLENGE.

The third dimension, *behavioural effectiveness*, looks at whether a process causes one or more of its participants to change their behaviour as a result of participating; while the fourth, *constitutive effectiveness*, concerns the extent to which processes give rise to increased social practice on the part of its participants. Both of these dimensions can be mapped onto the social outcomes evaluation element of the framework (Figure 2). These dimensions address the CAPACITY-BUILDING CHALLENGE.

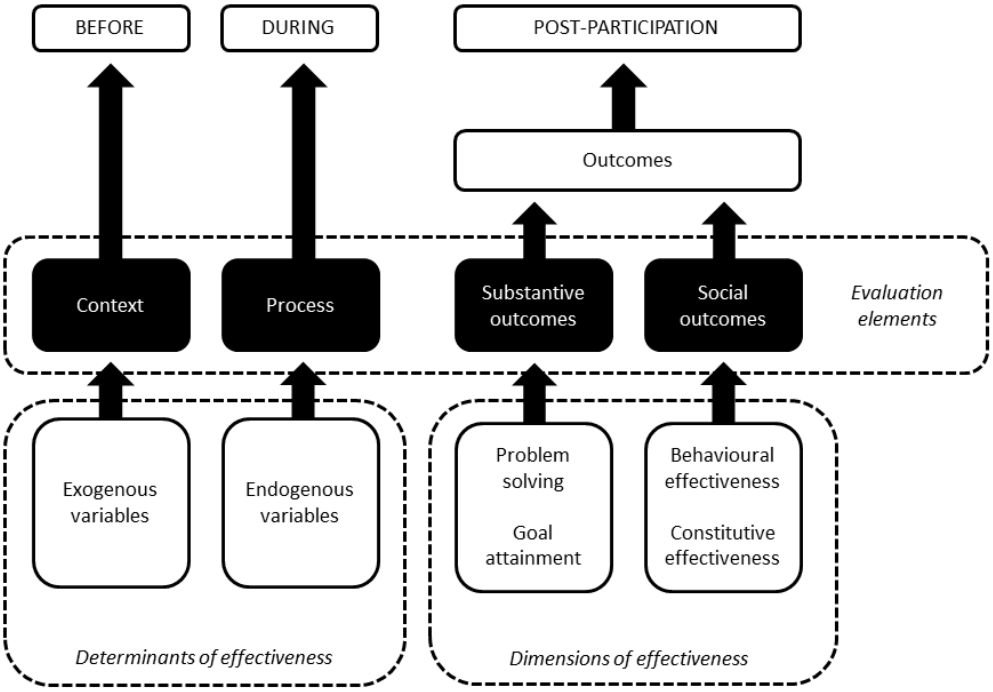


Figure 2: Framework for evaluating the effectiveness of participation in flood risk management

2.3 Determinants of effectiveness

To design participatory processes that achieve each of these dimensions, one must appreciate the variables that determine effectiveness. These can largely be divided into decision and structural variables (Young, 1994). Variables can be endogenous (attributes or properties of the process itself) or exogenous (driving forces that influence the course of the process and its outcomes). Decision variables are usually endogenous, controllable factors that can be manipulated by those responsible for designing and managing a process. These factors map onto the process evaluation element (Figure 2), where the aim is efficient design and ongoing improvement of the participatory processes such that these variables are controlled to maximise effectiveness.

Structural variables are usually exogenous features of the system that are outside of conscious control within the process lifespan, but which exert an influence over the effectiveness of both the process and its outcomes (National Research Council, 1996). Practitioners understanding influential structural variables are clearly at an advantage when designing processes that are well-adapted to the context in which they are expected to be effective (Young, 1994). Structural variables are explored using context evaluation, which supports the pragmatic tasks of informing technique selection, objective identification, and participant selection; by allowing the designer of the process to assess the potential for participatory modelling to be successfully employed. As a result, it is conducted before the participatory elements of the process, such that later elements can be adapted as the context requires.

By framing participation in terms of effectiveness one can identify what flood risk management requires of each evaluation element. However, to translate this understanding into an effective process in practice, criteria are required that are bespoke to flood risk management, but sufficiently flexible for use in a range of contexts.

3. Selecting evaluation criteria

A range of approaches exist for selecting evaluation criteria, of which a mix of theory-based and user-based evaluation are employed (Chess, 2000).

A theory-based approach is used to select criteria for evaluating context, process and social outcomes. This approach develops criteria from the literature, and applies them universally to participatory efforts (*cf.* Fiorino, 1990; Webler, 1995). By reviewing the wealth of literature on participatory processes, criteria grounded in best practice can be standardised. This is particularly important in participatory flood risk management, where many participatory modelling techniques have not been widely applied to the field (Voinov and Bousquet, 2010). In order to compare and contrast the relative merits of different techniques, standard process evaluation criteria are suggested. These criteria are kept deliberately generic; concerned with assessing the desirable characteristics of the process as opposed to the efficacy of the technique used. Similarly, theory-based evaluation criteria selection is used for social outcomes evaluation, where the literature on community resilience facilitates systematic evaluation across the range of contexts, variability in which is captured by context evaluation.

A user-based approach is adopted to select criteria for evaluating substantive outcomes. This method allows users to develop their own criteria, and is founded on the premise that different users will have different goals. Permitting users to generate their own criteria allows one to gain insight into what the flood risk community are hoping to gain from taking a more participatory approach and the extent to which different techniques can deliver on their goals. User-based evaluation adds credibility and usefulness to the overall evaluation by helping to ensure the diverse range of user needs are accommodated (Greene, 1987; Syme and Sadler, 1994).

4. Criteria for context evaluation

While context criteria are exogenous variables largely outside the control of those managing participatory processes (Figure 2), they often have a significant impact upon the success or failure of a process. The importance of context on the effectiveness of participatory processes is reinforced in the National Research Council's *Understanding Risk* report:

'…results depend less on the tool and more on its users and the setting in which it is used. […] The history of an issue, level of conflict, scientific data, and existing power dynamics may also influence the outcome as much as the method' (National Research Council, 1996, 96).

Several papers explore the contextual variables affecting participation, constructing criteria against which context can be evaluated (*cf.* Renn *et al.* 1993; Coglianese, 1997). This framework builds on four such criteria developed by Lampe and Kaplan (1999), drawing on other studies (Beierle and Konisky, 2000; Bier 2001) to provide examples of success statements (Table 2).

Table 2: Context criteria (after Lampe and Kaplan, 1999; Beierle and Konisky, 2000; Bier, 2001)

Criterion	Success statements
Understanding of the issue	The scientific and technical aspects of the problem are understood The risks of flooding are understood
Support from officials and community leaders	Local flood risk practitioners support participatory ways of working Local flood risk practitioners use the outcomes of participatory processes Residents support participatory ways of working Residents use the outcomes of participatory processes Residents trust those with responsibility for managing the issue/problem
History of past interactions	Local stakeholders often work together to solve problems/make decisions Pre-existing stakeholder relationships are positive Stakeholders' goals/views are similar Residents care about the issue/problem
Complexity of the dispute	The problem is simple A small number of agencies are responsible for the issue/problem There is a clear structure of roles, responsibilities and competencies The geographical extent is clearly defined and manageable There is consensus on how the issue should be managed

The importance of context can be exemplified with reference to the flooding of Thirlby, North Yorkshire, UK (Twigger-Ross *et al.* 2011). Thirlby is a small rural community (population 110), which experienced flash flooding in June 2005 after a period of intense rainfall. Water levels rose quickly and velocities were high, destroying roads in and out of the village, and leaving several residents cut off from external aid for several hours. Prior to the 2005 the flood risk facing Thirlby was poorly understood, as previous floods had been very minor (*Understanding)*. This led several residents to view the event as a 'one-off' (*Understanding*). Since the event, efforts by the Environment Agency to create an emergency plan to improve efficiency have met little support, with the majority of residents feeling that the community coped effectively (*Support*). The relative isolation of the community has resulted in a culture where the residents see themselves as self-sufficient and resilient (*History*), and although there is not a lack of trust in outside agencies, they are seen as slow and inefficient. In social capital terms (after Putnam, 2000), the bonding ties are very strong within the community, but the linking ties with external agencies are relatively weak (see Figure 5) (*Complexity*). Thoughtful and continued engagement with community leaders will allow everyone involved to learn from the lessons of the 2005 flood, and create a community which is more amenable to future participation.

5. Criteria for process evaluation

Process evaluation is aimed at ongoing improvement of the participatory process, and can provide feedback to users and facilitators during the development and implementation of participatory activities (Tuler and Webler, 1995; Chess, 2000). It is conducted using participant surveys; event or activity logs; key participant interviews; focus groups; meeting observation (including debriefing sessions); and reviewing of group documents (e.g. minutes, annual reports, attendance registers) (Beierle, 1999).

In this framework a theory-based approach to criteria selection is presented, with criteria drawn from good practice in the participation literature. Process criteria are derived using Fiorino's four principles of effective participation (Figure 3 and Table 2) (Fiorino, 1990). The principles developed by Fiorino are particularly suited to flood risk management, where governance and decision-making is being devolved to local government and greater emphasis is being placed on community resilience (*cf.* Steinführer *et al.* 2009; also Section 6). While these principles are strongly linked to arguments for increasing stakeholder participation, they fall short of evaluating the process design qualities that support both recruitment and retention of participants. Including quality as a fifth criterion helps to ensure that goals are defined early, clearly communicated and measureable; and highlights the importance of managing participant expectations. Recent findings from participatory research in the Great Lakes region, shows us that without measurable progress towards clear goals and objectives, stakeholders can become disillusioned with the process and may lose motivation and withdraw their support (Hartig *et al.* 2010).

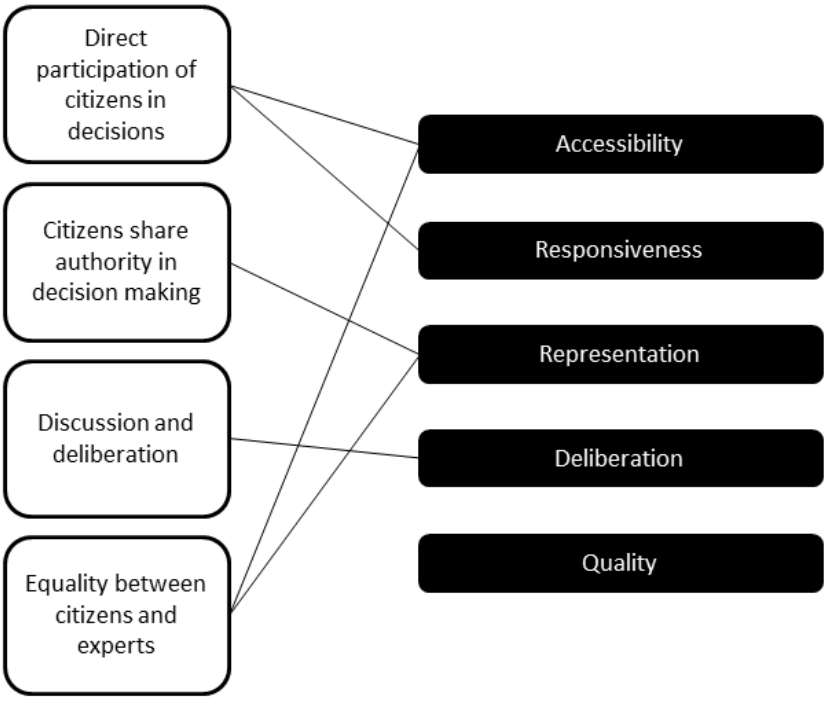


Figure 3: Development of process criteria (shaded boxes) from Fiorino's principles of effective participation (white boxes) (after Fiorino, 1990)

Table 3: Process criteria

Criterion	Success statements
Accessibility	Clear and frequent communication kept the modelling process transparent Participatory activities, resources and language were designed such that all participants could fully engage, regardless of skills and experience
Deliberation	Participatory activities fostered knowledge exchange, debate and consensus building
Representation	The participants are representative of the affected community and the full range of views All participants were given opportunity to make a substantive contribution
Responsiveness	The participatory process was flexible to change, with the agenda and activities shaped by the needs and goals of the participants Participatory tools were chosen according to local objectives, resources and available data

Quality	Participatory activities were facilitated in a professional manner
	The participants knew what was expected of them and what they could expect to gain from participating
	The process had clear purpose, objectives and direction

5.1 Accessibility

This criterion is about opening up the participatory process such that all participants can actively engage with activities in a meaningful way. An accessible process is one where participants can understand and use all of the information available to them, and use it to participate equally and in an informed manner (Webler *et al.* 2001). When participation involves elements of modelling, it extends to ensure that any activities conducted 'behind the scenes' are fully communicated to the participants in a clear and timely manner. Without this transparency, there is a risk that models become a black box, where the assumptions and shortcomings of the model are neither understood nor appreciated by non-expert participants (Prell *et al.* 2007). If local stakeholders are able to contribute to and challenge models as they are being built, they will understand the assumptions of those models, because they will be their own assumptions; they will appreciate the extent to which they can be used reliably; and appreciate the level of uncertainty in the model results (Voinov and Gaddis, 2008).

It is widely accepted that the technical and statistical language used in flood risk, particularly around uncertainty and likelihood, is a substantial barrier to engagement (Cotton *et al.* 2015). This is an issue that is currently being addressed by the Environment Agency (the UK national regulator) who are seeking to avoid the use of technical language and probabilities in their training materials, instead opting for a focus on visuals, stories, qualitative language and non-specific indicators of severity (EA, 2012). Ensuring that language and activities are accessible facilitates participation by individuals from socio-economic groups with low levels of education, which have been identified as among those most vulnerable to flooding (Burningham *et al.* 2008; Twigger-Ross *et al.* 2014). A study into public dialogue in Newcastle upon Tyne, UK further revealed that the translation of language and statistics into 'impact information' was required if participatory activities were going to be meaningful to those living in flood risk areas (Cotton *et al.,* 2015).

5.2 Deliberation

A deliberative process is measured by the quality of communication between participants (Beierle and Konisky, 2000) striking a balance between providing all participants with the opportunity to have their

views considered, and arriving at agreement on common goals and actions (Halvorsen, 2001). Webler *et al.* (2001) go on to argue that creating this space for deliberation and dialogue affords a process greater legitimacy, supporting the achievement of other process critieria (quality and responsiveness).

Until recently, flood risk management in the UK remained a largely scientific arena, drawing on expertise from local government, regulatory agencies, and increasingly, commercial consultancies (Haughton *et al.* 2015). Recent thinking values the contribution local knowledge can have to more accurate and effective mapping of flood risk, providing critical detail at the local level (McEwen and Jones, 2012; Twigger-Ross *et al.* 2014). Deliberation gives residents the opportunity to engage in open discussion with representatives from different agencies, building a positive working relationship and exposing any misconceptions about each other's responsibilities, capabilities and resources both in mitigating flooding and responding to an event. Practitioners have traditionally found deliberation difficult, requiring a shift in role from that of information giver to information co-producer, a difficulty likely exacerbated by the tradition of top-down governance and funding structures in the UK (Ashley *et al.* 2012).

5.3 Representation

While accessibility is concerned with designing processes that allow all participants to engage in a meaningful way; representation is about ensuring participants are representative of the community at risk. In particular, that the full range of flood risk knowledges are gathered, evaluated, and used to support recommendations (Beierle, 1999; Beierle and Konisky, 2000; Webler *et al.* 2001). It can be argued that members of a community who spend their daily lives interacting with a system will have privileged knowledge of physical and social systems (*cf.* Wynne, 1996), including flow paths taken by water in the early stages of a flood event; choke-points on local watercourses where debris accumulates and causes blockages; and the spatial distribution of highly vulnerable members of the community (Tapsell *et al.* 2005). This local knowledge and understanding of community structure allows them to contribute the critical fine detail to broader strategies developed by experts (Twigger-Ross *et al.* 2014); and provide an insight into how decisions are made locally during a flood event (O'Sullivan *et al.* 2012).

A dichotomy between local and expert knowledge is of limited usefulness, and risks the privileging of one knowledge type over another (see Somerset Levels example in Section 6.2.1). Recent research argues the importance of thinking instead of 'hybrid knowledge formations' (Haughton *et al.* 2015) where different knowledges are viewed as complementary, and processes are encouraged to strike a balance between expert practitioners and local stakeholders (Smith and Wales, 1999). Emergent practice shows the sharing of flood knowledge(s) is becoming more widespread (Haughton *et al.* 2015),

led by several high-profile attempts to co-produce flood risk knowledge from an integration of scientific and local perspectives (Lane *et al.* 2011; Ryedale Flood Research Group, 2008; Landström *et al.* 2011).

The Localism agenda in the UK has led to the sharing of responsibilities for flood risk management among newly created Lead Local Flood Authorities, the introduction of a partnership approach to funding (see Section 1), and seen a social turn towards community engagement and increased community-level action (Nye *et al.* 2011; Twigger-Ross *et al.* 2014). Cashman's (2009; 2011) work in Bradford, West Yorkshire, UK (which flooded in both 2000 and 2003) highlights many of the issues caused by the dispersal of responsibilities for flood risk management between a multiplicity of agencies; including, *inter alia,* the isolation of key actors and the creation of institutional barriers to participation (Cashman, 2011). Identifying and recruiting a representative group of stakeholders can help to rectify this lack of clarity regarding the roles and responsibilities of different agencies, and facilitate shared dialogue and networking (Twigger-Ross *et al.* 2014; Cotton *et al.* 2015).

5.4 Responsiveness

Lacking specific guidance on how processes should be structured, flood risk managers often turn to professional consultancies for advice (Haughton *et al.* 2015). This introduces the risk that experts arrive with a preferred methodology that they then shape to fit; a mentality summed up as 'when you have a hammer, everything looks like a nail' (Prell *et al.* 2007). This top-down, one-size-fits-all approach ignores the local context and the range of risk perceptions that exist in a community.

Voinov and Gaddis (2008) propose general guidelines for process design, arguing that the structure should be set by the goals of the participants, the available data, and the local time and resource constraints; thus emphasising the importance of context (Section 4). Often simple outcomes that can be easily communicated (see Section 5.1) are more useful than complex models with limited applicability, high set-up costs, and less available data for model calibration and validation (Voinov and Bousquet, 2010). In their Ryedale study, Lane and colleagues were careful to offer participants 'an opportunity to make something together', without being specific about what the outcomes would be (Lane *et al.* 2011: 24). This purposeful vagueness emphasised that the process was designed to co-produce knowledge, shifting the burden from trying to make an off-the-shelf model work, to developing a model directly suited to the local context. In terms of its substantive outcomes, the study developed a 'collective competence' (*ibid.* 32) within the participatory group, such that members could actively reengage with the flood risk decision-making process, which has previously arrived at an impasse between agencies and local stakeholders.

5.5 Quality

Given the time commitments required by participation, it is important to evaluate the features of a process (e.g. structure, leadership and organisation) that maximise satisfaction, supporting the recruitment and retention of a motivated group of participants. (Hartig *et al.* 2010). While the responsiveness of a process is important (see Section 5.4), participant expectations need to remain realistic (Webler *et al.* 2001). This is accomplished through clear direction, goals and milestones, which manage participants' expectations: both what is expected of them, and what they can expect to gain from participating (Chess and Purcell, 1999; Barreteau *et al.* 2010). Clear expectations help develop the trust that is fundamental to facilitating continued use of any outputs after the participatory process (Jakeman *et al.* 2006; Voinov and Bousquet, 2010).

Ideally, participants should be involved from the beginning of the process to help define a common vision for managing flood risk: providing input into the process aims, scope, and methodology (Chess and Purcell, 1999; Hartig *et al.* 2010). Building this shared vision can help to understand the complexity of the problem and lead to the emergence of innovative solutions (Ashley *et al.* 2012); improve the usefulness and credibility of the resulting outcomes; and foster ownership of local flood risk management interventions (Lachapelle and McCool, 2005; Voinov and Gaddis, 2008). This is exemplified in the case of Appleby-in-Westmorland, Cumbria, UK which was supported by the Environment Agency in the development of a flood action plan, including a procedure for distributing sandbags in a flood event (Harries, 2010). By working with, rather than imposing themselves on the community (which already considered itself highly resilient), the Agency were able to overcome previous distrust.

6. Criteria for outcome evaluation

The outcomes of a participatory process here include both the co-produced substantive outcomes of the process and longer-term social outcomes. Substantive outcomes include, *inter alia*: conceptual models of how the flood system operates; recommendations on which interventions, or combinations thereof, residents consider worthy of further exploration through traditional modelling methods; identification of misconceptions or knowledge gaps in the community; and consensus around what individuals and the community should be doing to minimise flood risk (*cf.* Chess and Purcell, 1999). Longer-term social outcomes are evaluated by making an assessment of three interacting social capacities (knowledge exchange, motivation to proactively reduce flood risk, and networking between stakeholders), which act as indicators of both the level of community resilience, and its potential to be enhanced (Pahl-Wostl *et al.* 2007; Höppner *et al.* 2010; Kuhlicke *et al.* 2011).

Several studies have shown that those responding favourably to a participatory process, may not respond favourably to outcomes (*cf.* Mazmanian and Nienaber, 1979), highlighting the need for evaluation of both process and outcome criteria, including longer-term influences of participatory efforts on social capacity, appreciating that 'exploring only immediately apparent programmatic outcomes may be short-sighted' (Chess and Purcell, 1999: 2691). The approach taken here considers substantive criteria developed from user goals, alongside social criteria grounded in social capital theory; advocating methodological pluralism, and overcoming the limitations of taking either single approach.

6.1 Substantive outcomes

Appling normative criteria to process and social outcome evaluations make studies easier to compare and improve upon. However in order for participants to see activities as worthwhile, evaluation needs to extend to those elements and results that have salience to them (Chess, 2000). It is therefore essential that substantive outcomes are evaluated against criteria that are developed by those who are responsible for using the outcomes of the process. This further allows outcome criteria to vary depending on culture, environmental problem, social and political history, and other context-specific factors (Chess and Purcell, 1999).

Understanding and monitoring the achievement of user goals can support the selection of techniques and activities that are best suited to achieving those goals. It also provides critical information about how closely goals are shared amongst different stakeholders; identifying potential areas of disagreement and conflict, as well as any common ground that can be used to develop trust between participants. It is to some extent inevitable that participants will continually adjust their goals and expectations as a participatory process unfolds, in response to a realisation of what the technique can realistically achieve given time, resource, data, expertise and other constraints. A strong evaluation of substantive outcomes will give participants the opportunity to comment on any unexpected outcomes, as well as providing information on any shortcomings.

6.2 Social outcomes

Increasing frequency and severity of flooding in the UK has led to concern surrounding societal exposure and vulnerability to flooding (Brown and Damery, 2002). Where much effort has been focussed on understanding current and future trends in hazard exposure, less has been spent on addressing the factors that make people more or less vulnerable to losses in their well-being (Lindley *et al.* 2011). Vulnerability is defined here as the 'pre-event, inherent characteristics or qualities of social systems that create the potential for harm' (Cutter *et al.* 2008) and arises from an individual's lack of resistance

(ability to counteract the immediate effects of flooding and not be adversely affected), and/or resilience (capacity to function, recover and adapt following a flooding event).

Although the social factors affecting vulnerability are well documented (*cf.* Morrow, 1999), vulnerability is primarily addressed using resistance strategies, which are most appropriate for hazards that are easily predictable and occur with some frequency, and unlikely to be fully effective against unprecedented or surprise events (Longstaff, 2005). In these events, such as flooding from intense rainfall, it is generally accepted that the system will undergo a period of transient distress, followed by a return to pre-event functioning (Flynn, 1994). Resilience strategies are slowly reflecting this thinking, advocating adaptation (not mere stability) in response to change (see Figure 4), thus ensuring that any pre-existing vulnerabilities are not reproduced through the recovery process (Norris *et al.* 2008; Twigger-Ross *et al.* 2014). It is particularly important in flood risk that we consider how participation might be used to build community resilience at different phases in the flood event cycle (see Figure 4).

In evaluating a participatory process we are interested in seeing not only how community resilience has changed, but also whether it is more or less likely to increase in the future as a result of that participation. We here propose that an assessment of community resilience be attained by evaluating three interacting social capacities: knowledge exchange, motivation to proactively reduce flood risk, and networking between stakeholders (Figure 4) (Buchecker *et al.* 2013; *cf.* Norris *et al.* 2008). Social capacities are 'the features of social organisation, such as networks, norms, and trust that facilitate coordination and cooperation for mutual benefit' (Putnam, 1993, 35), which are built through an iterative long-term process of (re-)discovering, enhancing and developing a community's resources and abilities (Wenger, 1999; Kuhlicke *et al.* 2011). Taken in combination, these three capacities interact to determine the way in which a community can prepare for, resist the impact of, respond to and recover from a flood event, in other words, determining their level of community resilience (Figure 4).

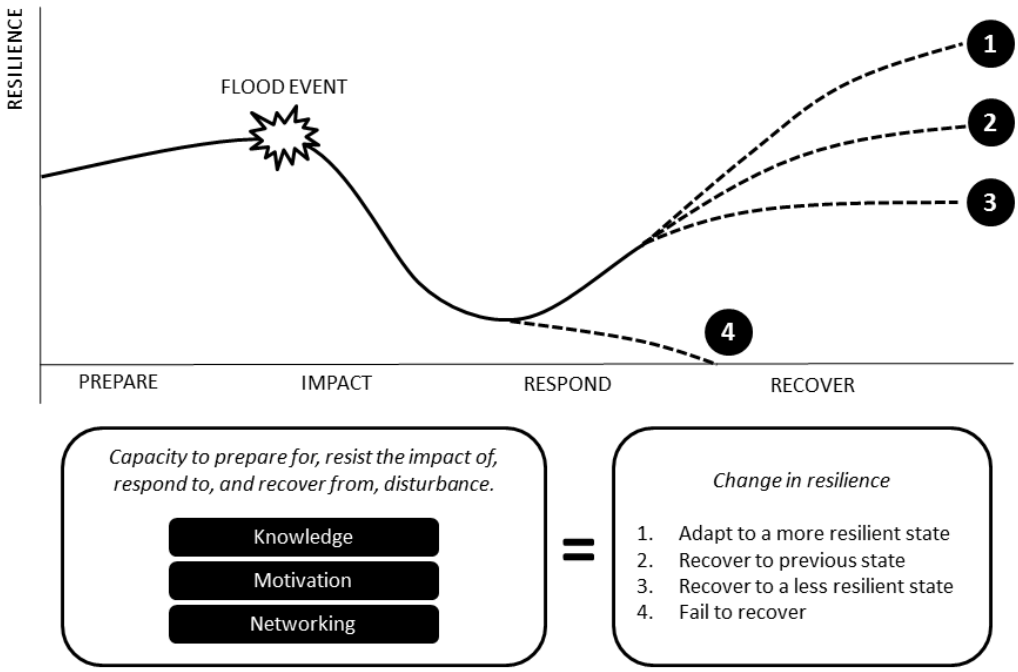


Figure 4: Interacting social capacities effecting a change in resilience (modified after Cutter *et al.* 2008; DFID, 2011; Buchecker *et al.* 2013)

Building flood risk resilience is a primary goal of increased participation and often the justification for opening up the decision-making process to the participation of local stakeholders in the first place (*cf.* Beierle, 1999). By evaluating the form and quantity of social capital in a community, conclusions can be drawn about the existing level of community resilience, and the potential for it to increase over time. The aim is for participatory efforts to foster an environment in which social capacities are maximised, such that when faced with challenge or shock, as in the case of a flood event, social capital can be utilised by the community to reduce exposure and vulnerability. Through a review of the social capacity literature, success statements are offered as indicators that each of the three social capacities (Buchecker *et al.* 2013) is present and/or being developed (Table 4), with different emphases placed on each of the three capacities to reflect local goals and priorities. These statements are designed to be used before and after a participatory process, to assess whether any change in these capacities has occurred as a result of participating.

Table 4: Social outcome criteria

Criterion	Success statements
Knowledge exchange	I have the opportunity to share my knowledge on local flood risk with those responsible for decision-making
	I have the opportunity to discuss perception of risk with those responsible for decision-making
	I am aware of the range of interventions that are used (or could be used) to reduce flood risk in my community
	I know what to do in a flood event to reduce risk to my property and possessions
	I know what to do in a flood event to reduce risk to me as an individual
	I know who to go to for support/advice before, during and after a flooding event
Motivation to reduce flood risk	I take a proactive role in managing my individual flood risk
	I take a proactive role in managing flood risk in the wider community
	I am aware of a range of appropriate interventions that I could implement individually or with the community
	I feel that my ideas, knowledge and experience are valued by decision-makers
Networking between stakeholders	I have positive relationships with others in the community that are affected by flooding
	I have positive relationships with flood risk decision-makers (both within and outside of the community)
	I understand roles and responsibilities of the different individuals and agencies that manage flood risk in the community
	I trust those with responsibility for managing flood risk in the community
	I understand roles and responsibilities of different individuals and agencies during a flood event

6.2.1 Knowledge capacity

Flood risk management is increasingly moving away from stressing the primacy of scientific knowledge and advocating the 'technical fix' for reducing flood risk (Brown and Damery, 2002); towards a growing appreciation for the tacit knowledge held by individuals who interact with systems on a daily basis (Berkes *et al.* 2000; Folke *et al.* 2005). To facilitate this shift, the role of participation changes from one of knowledge delivery to one of learning and knowledge co-production (Folke *et al.* 2005), a change that requires participation to facilitate the building of knowledge capacity at the individual and community level (Höppner *et al.* 2010).

The dangers of failing to understand public perception of flood risk were made clear in the flooding of the Somerset Levels (a large, flat area of reclaimed agricultural land) in the UK in the winter of 2013-14. During the event, a dichotomy emerged between local and expert knowledge, centred on whether the flooding has been exacerbated by a reduced drain clearance regime imposed by national agencies. Management of flood risk on the Somerset Levels was simplified by the media to the single question of 'to dredge or not to dredge?' (Fitzpatrick, 2014), and pressure was placed on central government to promise a new programme of drain clearance despite lack of clear scientific evidence over its effectiveness (Haughton *et al.* 2015; Fitzpatrick, 2014). Examples such as this support the argument that privileging of one type of flood risk knowledge over another (e.g. local knowledge over expert knowledge) leads to poor policy decisions (Lidskog, 2008).

Novel approaches in Pickering, Yorkshire are introducing ways in which local stakeholders can engage in the co-production of flood risk knowledge, drawn from both local and expert sources; and are at the leading edge of creating and utilising a 'hybrid knowledge' of flood risk (Lane *et al.* 2011; Landström *et al.* 2011; Ryedale Flood Research Group, 2008; Haughton *et al.* 2015).

6.2.2 Motivation capacity

Building social capital requires members of the community that are motivated to engage with community activities and initiatives designed to reduce flood risk. In the event of flooding, these individuals create an 'informed, capable, critical mass' and are those most likely to act as community champions or peer educators (O'Neill, 2004; Deeming, 2008). While motivation can be attributed to a range of psychological and social drivers (*cf.* Miles *et al.* 1998), the highest levels of motivation capacity are found in communities where sharing knowledge and supporting one another are viewed as moral obligations; with opportunities for community members to play meaningful roles in the management of local flood risk.

The benefits and barriers to participating in community activities aimed at reducing flood risk are exemplified in the case of Southwell, Nottinghamshire, UK (population 4500). Following a major flooding event in summer 2013, a local flood action group formed out of residents' motivations to reduce flood risk in the town. The group quickly affiliated itself to the National Flood Forum, a national charity set up to support and guide the activities of local flood action groups across the UK, becoming Southwell Flood Forum (SFF). SFF coordinates community activities, such as the clearance of local watercourses and management of emergency road closure schemes, liaising with local flood risk management agencies. Motivational barriers to participating in the activities of the SFF include: persisting attitudes among some residents that responsibility for managing flood risk lies with local and national agencies; a lack of appreciation of the wider potential benefits of their own actions towards reducing flood risk and increasing resilience, especially among those residents and riparian owners who weren't flooded themselves; and a hesitancy to contribute where residents doubt the value of their non-technical, local, experiential and historical knowledge (Jacky Huson, personal communication, 2014).

6.2.3 Network capacity

The networks that foster the formation of social capital were popularly categorised by Putnam (2000) into bonding, bridging and linking ties (Figure 5 and Table 4). It is argued that communities dense in all three of these ties are those that will also contain the full range of individuals required to form strong, effective and long-lasting community groups capable of delivering resilience during and after a flood event: (i.e. those with high network capacity) (Folke *et al.* 2003).

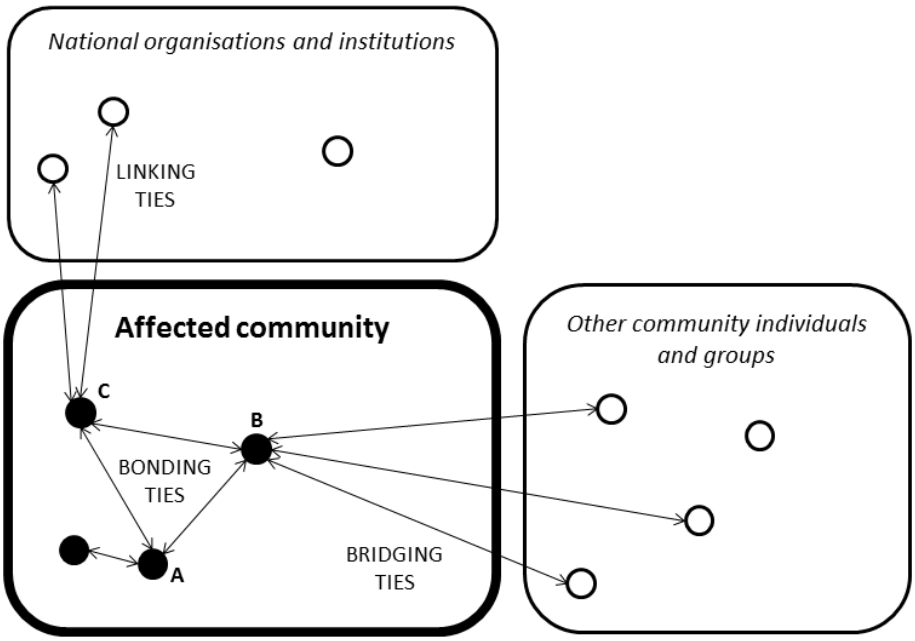


Figure 5: Bonding, bridging and linking ties as a model for building network capacity

Table 4: Definitions of the ties that form network capacity

Type	Definition	Example (see Figure 5)
Bonding	Relationships between individuals with a shared social identity. They are often observed immediately following a flooding event, when individuals withdraw from wider society and rely on close-knit groups, thus reducing exposure to perceived external risks.	Person A, with strong bonding ties represents an altruistic individual, with strong social skills, whose closeness to those around them has accumulated an understanding of local needs and aspirations that constitutes a 'community history'.
Bridging	Relationships of continued exchange, whereby individuals are connected more by common interests or goals than by their social identity.	Person B, with strong bridging ties, is an individual with a great diversity of acquaintances, who can use their connections outside of the immediate group to facilitate the sharing of information, knowledge and skills.
Linking	Relationships typified by an explicit vertical power differential. Linking ties with organisations and national institutions promote participation by transferring management rights, and therefore power, downwards.	Person C, with strong linking ties, is the individual who can 'make things happen' by maintaining partnerships with regional and national institutions who often act as sources of experience, funding and certified expertise.

Participatory processes have the potential to enhance network capacity. During flooding events, the critical factor determining the success of the emergency response is the way in which the community works with and alongside national agencies, local government, emergency services and the media (Brown and Damery, 2002). This can be exemplified using the case of Wraysbury, Berkshire. Wraysbury is a small community (population 3500) by the River Thames, 18 miles west of London. Following the onset of flooding on 7 February 2014, it was not until four days later (following a confrontation on Sky News with the Defence Secretary, Phillip Hammond) that outside agencies and the armed forces arrived to provide emergency assistance to the village (Su Burrows, personal communication, 2014). In the intervening time, 84 of 103 homes in Wraysbury had been evacuated, and the worst of the damage had been done. A small, dedicated group of local individuals relied on their bonding and bridging ties within the community to provide feelings of emotional connectedness and support (Putnam, 1993; Berkman and Glass, 2000); maintain information flows (Pelling and High, 2005); and facilitate collective action (Putnam, 2000). Those coordinating the emergency response efforts later reflected on the need to enhance linking ties in order to better structure their response and allocate resources (including information). For example, improved knowledge of how to request Military Aid to the Civil Community which mobilises intervention by the armed forces, could have sped up the provision of external emergency assistance to the community (Su Burrows, personal communication, 2014).

7. Conclusions and implications for practice

While top-down approaches to building flood risk resilience have been developed, such as the recent Floods Directive (European Commission, 2007), the procedural nature of many legislation instruments make it difficult to move towards a more participatory approach. Notably, no process or criteria for evaluation is given in the participation element of the Directive. This paper is a first step towards addressing this deficit.

Participation in flood risk management forms an iterative cycle (Figure 1), in which the assessment of different elements is required in order for an evaluation to be complete and holistic. Four distinct evaluation elements are identified: context, process, substantive outcomes, and social outcomes. Special distinction is made between process and outcomes to address the findings of several papers, in which it has been shown that stakeholders responding favourably to a participatory process may not respond equally favourably to outcomes.

This paper presents criteria for each of these elements, and examples of success statements that might be used in a practical assessment. While these statements are by no means exhaustive, and can be developed as experience is gained, they provide a starting point for framing the scripts used to elicit

participant opinion through mechanisms such as participant survey, semi-structured interview or on a workshop evaluation form. The framework further ensures evaluation remains a focus of participation before, during, and after the process; appreciating that the outcomes of any participatory process, both social and substantive, will shape the context of the next (Figure 1).

Process evaluation provides a standard assessment of all participatory activities, based on five desired characteristics: accessibility, deliberation, representation, responsiveness, and quality. Context evaluation captures information about the landscape in which these participatory activities are set, and whether that landscape promotes or discourages participation. It is carried out by the organiser/facilitator before the participatory process, as the results of context evaluation can be used to support the design of a process that best meets local needs, resources and existing capacities. It further captures the range of participant goals, which can be later revisited in the evaluation of substantive outcomes.

Substantive outcome evaluation develops success statements in collaboration with the end users of these outcomes, which may include, *inter alia*: conceptual or numerical models, recommendations, formal emergency plans and/or risk communication materials. It will provide a context-specific assessment of how far the substantive outcomes of a process address the goals identified in the context evaluation. By developing criteria in collaboration with end users, evaluation is extended to capture those elements and results that are of greatest significance to them.

Finally, social outcome evaluation proposes that an assessment of community resilience can be attained by evaluating a set of three interacting social capacities: knowledge, motivation and networking. Taken in combination, these capacities interact to determine the way in which a community can prepare for, resist the impact of, respond to and recover from a flood event, in other words, indicating their level of community resilience. They are designed to be used before and after a participatory process, to assess whether there has been any change as a result of that participation.

This paper moves towards a framework for evaluating the use of a participatory approach (and its associated techniques) in flood risk management. Detailed and consistent evaluation of applications can support practitioners with choosing the most suitable technique to apply in a given context; what to expect that technique to deliver; and provide a clear indication of whether or not it has been successful. With the vast range of techniques available to practitioners, and the complex and context-specific nature of flood risk, providing advice of this nature is critical to providing more legitimate, democratic and inclusive participatory processes.

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7. Conclusions

7.1 Summary

At the outset, this thesis proposed four research questions (RQs) (Figure 1.4, p25). RQ1 asked what flood risk management was seeking from participation, and particularly from a more active form of participation that involves local stakeholders throughout the flood risk decision-making process. This relates closely to RQ2, which asked what participation can be expected to realistically deliver. Both of these questions formed the basis of Objective A: the construction of a framework to assess different participatory techniques, and their ability to deliver the qualities that are sought in contemporary flood risk management. The framework developed in this thesis (Paper I) identified two key challenges, accessibility and complexity, which appear to compete, but which must both be overcome if participation is to be effective. It went on to critically review the flood risk management literature, identifying five metrics that could subsequently be used to compare different participatory techniques: accessibility, transparency, adaptability, evaluation and holism; reflecting five qualities that were consistently valued in contemporary flood risk management. Finally, the framework critically assessed three participatory modelling techniques against these metrics, to provide an early indication of which techniques might be suited to which stages in the decision-making process (Figure 2.1, p32).

Addressing RQ3, which asked what participatory modelling techniques can offer at different stages in the flood risk decision-making process, required a change in methodological approach. The question narrowed down the field of study, and set the stage for a case study approach, exemplifying two popular techniques. This exemplification provided a practical test of the theoretical framework (Paper I), and substantiated the claims it made. Where RQ1 and RQ2 prompted early theoretical arguments for what participation could potentially deliver, RQ3 was answered through Objective B: the piloting and evaluation of two participatory modelling tools in local flood risk contexts. In the first case study, a Bayesian network model was co-produced with local stakeholders in Hebden Bridge, West Yorkshire, UK, to test the efficacy of the technique for identifying and exploring different flood risk management interventions (Paper II). In the second case study, elements of system dynamics were used to develop understanding of risk dynamics following a recent flooding event in Southwell, Nottinghamshire, and support local stakeholders with a review of community-scale resilience measures (Paper III).

A final research question RQ4, dealt with evaluating the effectiveness of participatory modelling techniques. Although the theoretical framework constructed in response to RQ1 and RQ2 provided a basic indication of what flood risk management was seeking from participation, a more holistic evaluative framework was sought, which assessed the context, the process and its outcomes (both

short-term substantive gains and longer-term social changes). Constructing this framework, and populating it with practical criteria became Objective C, and is reported in Paper IV.

7.2 Contribution to knowledge

In responding to the four research questions summarised above, this thesis makes the following contributions to knowledge:

1. A framework for the critical review of participatory methods, which differs from existing frameworks in environmental management by assessing methods against metrics derived from those qualities sought from participation in contemporary flood risk management.

2. Detailed reports of two UK case studies, exemplifying how different participatory modelling techniques can support the active involvement of local stakeholders in flood risk management at different stages in the decision-making process, and providing evidence for the refinement of both the theoretical and evaluative frameworks developed in (1) and (3).

3. An evaluative framework that is holistic and transferable, moving beyond the process-centric frameworks currently available, and providing practical criteria by which to assess the effectiveness of participatory techniques in different flood risk management contexts. Furthermore, the application of said framework to two UK case studies at different stages in the decision-making process (2).

7.3 Detailed conclusions

Objective A: Framework

Construct a framework for involving local stakeholders in flood risk management that explores the efficacy of different participatory modelling techniques to deliver the qualities of participation that are sought in contemporary flood risk management.

1. *The benefits of active participation are well documented, and this has resulted in both demand and enthusiasm for active participation in flood risk management (Paper I, Section 2, pI—3)*

2. *Participation in flood risk management faces two competing challenges: accessibility and complexity (Paper I, Section 1, pI—2)*

This presents a double-edged sword, whereby flood risk management seeks participatory techniques that are accessible to a range of stakeholders with limited or no technical expertise, but these techniques must ultimately be able to structure knowledge about a complex system with multiple, interrelated elements.

3. *Participatory modelling offers a suite of techniques that have the potential to address these challenges (Paper I, Section 3, pI—4)*

The capacity of participatory modelling techniques to meet these challenges is assessed on the basis of five quality metrics: accessibility, transparency, adaptability, evaluation and holism. The first two of these primarily address the accessibility challenge, while the latter three deal with complexity.

4. *There are few, if any, examples where participatory modelling techniques have been applied to flood risk management.*

This is arguably due to a lack of knowledge and understanding of the techniques that exist, and how each technique might support and complement existing decision making processes.

5. *To support local stakeholders, it is suggested that participatory modelling techniques are embedded within a broader participatory approach that contains several common elements (Paper I, Section 4, pI—8)*

The outcomes of research conducted in writing this thesis establishes that it is possible to nest participatory modelling within a three-stage participatory process, consisting of stakeholder analysis and goal-setting (Stage 1); model development (Stage 2); and model testing and validation (Stage 3). These stages are common to all participatory modelling processes, and create a framework which is sufficiently flexible to allow a range of techniques to be embedded within it.

6. *Participatory modelling techniques differ in their ability to deliver each of the five metrics identified in [point 3], and are thus suited to different parts of the flood risk management decision-making process.*

Three popular techniques were reviewed in Paper I: Bayesian networks, system dynamics and fuzzy cognitive mapping. Paper I discussed the strengths and limitations of each technique, exploring the extent to which they can deliver each metric. While it was beyond the scope of Paper I to explore the flood risk management decision-making process, for completeness this is outlined in the extended abstract (Sections 2 and 4), with the five qualities mapped to its different stages (Table 2.3, p44).

Bayesian networks have particularly strong adaptive and transparent qualities, meeting the accessibility challenge through systematic treatment of uncertainty and the complexity challenge through its technical strengths, including two-way reasoning and local updating (Paper I, Section 5.1, pI—14)

System dynamics have particularly strong evaluative, adaptive and holistic qualities, offering accessibility through user-friendly software with intuitive graphical user interfaces, and complexity though a focus on system structure and behaviour (Paper I, Section 5.2, pI—19)

Fuzzy cognitive maps are highly evaluative and holistic, but score poorly on accessibility and transparency. The accessibility challenge can be overcome through professional facilitation, while complexity is supported by taking advantage of the ability to integrate models (and hence viewpoints) contributed by individual stakeholders (Paper I, Section 5.3, pI—23).

Objective B: Exemplification

Use the frameworks created in Objectives 1 and 2 to trial and evaluate different participatory modelling tools in local flood risk contexts; specifically

i. Exemplify how Bayesian networks can be embedded within a participatory approach, to support options identification and exploration in local flood risk management.

1. *The case study site was selected to support engagement with a community with a history of frequent (and recent) flooding events; a high level of motivation for managing flood risk locally; and a desire to think beyond traditional engineering-led methods of managing flood risk*

While Hebden Bridge has received much media focus as a result of frequent significant flooding events, the community remains at significant risk of flooding. A series of modelling-centred studies has failed to find an engineered solution that is cost-effective. Following two flood events in summer 2012, the community were highly motivated to take a more active role in flood risk management, and participate in the identification of a range of innovative, yet appropriate, intervention options.

2. *The identification of interventions is a key stage in the flood risk management decision-making process (Figure 2.1, p32) that can be supported by participation*

Options identification is an early stage in the flood risk management process, which follows steps concerned with problem definition and establishing decision-making criteria. The linear nature of the decision-making process preceding options identification (see Figure 2.1) calls for active participation to ensure representative framing of the problem and the identification of novel interventions.

3. *The governing principles of the case study (Paper II, Section 3) maximise the opportunities for collaboration and capacity-building (Figure 1.2, p19)*

Three principles set out clear goals for the study. Collaboration was guided by principle one, which states that the model be co-produced by all participants; principle two, which stresses the importance of accessibility; and principle three, which makes a case for a pragmatic process structure that reduces the time and resource demands placed on the participants. Capacity-building was guided by principle two, which states that the modelling process be sufficiently transparent that participants can continue to use the model after the study.

4. *The case study aimed to (i) establish a set of catchment management objectives; (ii) co-produce a formal model of participants' understanding of local flood risk and the potential interventions to mitigate it; and (iii) to use said model to explore how interventions might achieve each of the catchment objectives*

5. *A Bayesian network model was selected as the participatory modelling tool because of its accessible, graphical nature and the ability to perform two-way reasoning*

The capacity for two-way reasoning was valued as an essential requirement for local flood risk management options identification, where the objective of the exercise is to identify which interventions, if implemented, offer the greatest likelihood of delivering the local flood risk objectives. It further facilitated exploration of the performance of alternative options under a range of socio-economic futures.

6. *Evaluation of the study showed Bayesian networks to be a valuable tool for assessing a broad range of potential intervention options*

Specifically, the technique enabled participants to identify interventions that might merit further investigation/appraisal. This was primarily achieved by performing backwards propagation – a technique which investigates the likely causes of a particular effect, given evidence that it has occurred. The technique was further praised for its ability to combine tacit, local knowledge alongside that of technical experts.

7. *Several limitations were found, the most notable being that the range of abilities and experience in the stakeholder group necessitated high levels of conceptual and numerical simplification*

These simplifications included the limitation of variables to binary states, to reduce the number of potential combinations for which conditional probabilities had to be calculated. It further included extrapolation of conditional probabilities from a subset elicited from stakeholders. This greatly reduced the time stakeholders spent populating conditional probability tables, although the technique used has received a mixed response from academic reviewers (see Paper II, Section 5.3, pII—17).

ii. Exemplify how elements of system dynamics can be embedded within a participatory approach, to support local governance of flood risk and the building of community resilience.

1. *The case study site selected for this element of the study was chosen to support engagement with a community much further along in the decision-making process (Figure 2.1, p32), where individuals and local organisations are currently seeking to evaluate and build on community intervention options*

Southwell, Nottinghamshire was chosen as the location of the second case study. The community had recently experienced a significant flooding event (July 2013), which was a combination of fluvial and surface water flooding from minor (ordinary) watercourses. As a result of that event, a highly proactive flood action group was established to organise the community response, to complement traditional flood defences that were currently being planned.

2. *The case study aimed to (i) identify the different receptors at risk and how risk to those receptors changed in the 2013 flooding event, and (ii) produce a cause-effect model to explore the efficacy of different community intervention options (including a review of options already being implemented)*

The focus of the model was to manage impact to receptors, by reducing their exposure and vulnerability to floodwater. Conventional numerical modelling was being conducted in other studies with the aim of identifying feasible options to manage the sources and pathways of flooding. In the context of that modelling, managing the residual risk that would remain once the flood defences were in place was seen as the responsibility of individuals and local organisations that make up the 'community'.

3. *The paper piloted a new stakeholder typology bespoke to meeting the challenges facing local flood risk management*

This typology, developed in Paper I, classified stakeholders according to three criteria (affection, responsibility and expertise) and then prioritised those stakeholders that exhibited two or more of the criteria. As a result, it placed equal weighting on expert practitioners (stakeholders with technical expertise) and local experts (stakeholders with tacit knowledge of the flood risk system).

4. *System dynamics was selected as the participatory modelling tool as a result of its focus on diagrams, and a range tools for exploring temporal dynamics*

Of particular interest was the ability to capture and explore how perceived risk changed over time during the 2013 event, as a result of flood water depth. This ability would allow the model to go on to be used to explore perceived risk in events of different durations and magnitudes.

5. *A model was co-produced by residents to explore the current situation and three possible, future scenarios, which were representative of current management strategies*

These scenarios included road closures, watercourse clearance, and property level protection. All three of these management strategies are currently used to some extent in Southwell, to reduce exposure and/or vulnerability to floodwater.

6. *Evaluation of the study revealed that the technique offers opportunities to maximise both the collaboration and capacity-building offered by participation*

The study maximised opportunities for collaboration by capturing local perceptions of risk, facilitating exchange of knowledge between residents living in or near spatially discrete risk hotspots, and giving local organisations a platform from which to build consensus over community resilience strategy. From a capacity-building perspective it gave residents a forum in which to share their experiences and views on different management options, engage with new residents, and strengthened partnerships between local organisations (most notably between Southwell Flood Forum and Nottingham Trent University).

7. *Several modifications and simplifications were required as a result of a failure to identify feedbacks during the model development stage – however this did not impede the ability of the study to meet its aims [point 2]*

These modifications included the reorganisation of the model structure into a simpler linear structure (see Paper III, Figures 12 and 13), and the construction of a separate model for each risk hotspot (although flow routes were well understood, participants struggled with how to quantify risk moving from one location to another). It is likely that feedbacks and/or stock and flow simulation models would be useful in some contexts, however the modifications made in Southwell were necessary to maintain an appropriate level of accessibility, while not comprising the ability to identify how risk changed over time [point 4].

Objective C: Evaluation

Present an evaluative framework for assessing the effectiveness of participatory processes in flood risk management; and populate that framework with practical criteria that are transferable to different contexts.

1. *For the purposes of developing an evaluation framework, participation in flood risk management is viewed as addressing two key challenges: collaboration and capacity-building (Paper IV, Section 1, pIV—2)*

The collaboration challenge requires that participation brings together local stakeholders and facilitates the sharing of knowledge and expertise on flood risk. The capacity-building challenge calls for building understanding and expertise at the local level, such that local stakeholders can play a more active role in the management of local flood risk. Specifically, local stakeholders could be more actively engaged in a host of local actions before, during and after a flooding event, including the identification and support of vulnerable receptors, and encouraging the uptake individual and community protective measures that expedite flood recovery.

2. *Most evaluation studies focus on the normative benefits of participation, where flood risk management seeks an extension of evaluation to include both substantive and instrumental gains*

3. *Achieving a holistic evaluation of participation processes requires a broadening of focus, beyond previous studies that are often limited to evaluating the quality of the process itself.*

A more holistic evaluation is sought which, in addition to assessing the quality of the participatory process, takes account of the context in which the participatory process is set, and to what extent outcomes of the process are met. These outcomes include both user-derived, substantive outcomes and longer-term social outcomes, which focus on the building of flood risk resilience.

4. *Participation is explored through the concept of effectiveness, which has a range of dimensions and a range of determinants (Paper IV, Section 2, pIV—5)*

Four dimensions of effectiveness were explored: problem solving, goal attainment, behavioural effectiveness, and constitutive effectiveness. The first two of these were assessed through the evaluation of substantive outcomes, and the second two through social outcomes.

5. *The selection of evaluation criteria can be theory or user-based. It is argued that theory-based criteria are suited to context, process and social outcomes; whereas user-criteria is adopted for substantive outcomes (Paper IV, Section 3, pIV—8)*

6. *Context criteria can significantly impact upon the success or failure of a participatory process (Paper IV, Section 4, pIV—8)*

The criteria include the current level of understanding of flood risk, support from officials and authorities for participatory processes, the history of past interactions between stakeholders, and the complexity of the problem being discussed. Understanding the contextual setting in which participation is planned supports the design of the process, such that it can be given the greatest possible chance of recruiting and retaining a representative group of participants, ensuring realistic goals are set, and allowing participant expectations to be adequately managed. As such, context criteria provide the organisers of a participatory process with critical information about the local context prior to process design, and enhances, as stated in the objective, the transferability of the evaluative framework between different areas.

7. *Process criteria help to ensure that processes are effectively designed, in order to recruit and retain a motivated group of participants (Paper IV, Section 5, pIV—10)*

In previous studies, process criteria have made up the majority of evaluations with a focus on participation. Here they are presented as one of four evaluation elements, and include accessibility, deliberation, representation, responsiveness and quality. Criteria are drawn from the literature on evaluation and participatory modelling, and where possible, tailored to the specific needs of flood risk management. While this thesis argues that evaluation must progress beyond evaluating the process in isolation, strong process design remains essential for connecting with local stakeholders, and keeping them engaged throughout the process. Providing managers with a standardised set of process criteria, derived from examples of good practice in literature, ensures that the process evaluation is consistent when applying different participatory modelling techniques. It helps to ensure that the basics of good participatory design are adhered to, and allows process managers to focus on the outcomes of participation, identifying what different techniques can deliver in different contexts (see point 6).

8. *Social outcome criteria assess indicators of community resilience, and help ensure that participation addresses vulnerability to flooding (Paper IV, Section 6, pIV—15)*

Social outcomes assess the dimensions of effectiveness that involve social changes as a result of participation, specifically changes in the behaviour of individuals and organisations (behavioural

effectiveness) or the development of relationships both within and outside of the community (constitutive effectiveness). As a proxy for these long term social changes, three interconnected social capacities were evaluated: knowledge, motivation and networking. These capacities provide an indication of the existing level of community resilience, and the propensity for it to increase over time. Social outcome criteria support managers with assessing the effectiveness of participatory processes, and allows comparisons to be made between cases by standardising social objectives. It is recognised that social goals may vary between cases, and these differences are addressed through the adoption of user-based substantive outcome criteria, which are bespoke to local priorities and objectives. When taken together, social outcome and substantive outcome criteria can provide a more holistic evaluation of participation than has been possible when using previous frameworks that focus largely on the process itself.

7.4 Recommendations

1. Manage expectations

The potential benefits of participation are widely known and commonly cited in a range of fields, however rarely are the limitations of participation acknowledged quite so openly. Those looking to more active participation to engage with disillusioned stakeholders who feel excluded from several stages of the decision-making process, can take the romanticised view that active participation can provide all of the answers. This is not the case – most participatory techniques, including those used in this thesis, are not sufficiently robust to make predictions about the efficacy of flood risk interventions, or used to identify the best solution. Their usefulness must be measured in different ways (point 3). The value of participatory techniques exists in their ability to bring together a wider range of local stakeholders as a result of their accessibility, and capture the tacit knowledge that they possess, reporting it in a way that is structured, considered, and fully aware of its limitations. Used in conjunction with established numerical modelling, they can provide complementary evidence on public perception of risk, identify local priorities, and highlight misconceptions in local understanding. Where local stakeholders are those tasked with risk governance (e.g. the organisation of individual and community-scale interventions designed to build resilience), participatory techniques provide novel and systematic support with collating, interrogating, and presenting local knowledge.

2. Be prepared to simplify

In both case studies reported in this thesis, it was necessary to make significant simplifications to the techniques being used, such that accessibility was maintained. Although changes may result in reduced functionality, model simplifications, model assumptions, and introduce greater uncertainty in model outputs, any loss of accessibility would have impinged on the overall aim of involving local stakeholders in the decision-making process. Assuming that simplifications will need to be made to how a technique is applied, it is unlikely that the technique used will achieve all of its reported benefits. Those managing participation processes should be aware that models and other outputs produced through participation may lack scientific robustness, be high in uncertainty, and representative of the views of a small subset of the community. They must therefore be open to different metrics of success (point 3), when evaluating whether a participatory process has been effective.

3. Be open to different metrics of success

This thesis clearly argues that participatory processes will not replace traditional flood risk modelling, which requires specialist, technical expertise and experience. However, if flood risk managers are open to different metrics of success, then participatory processes and their outcomes may be viewed as

complementary to more traditional practices. Models co-produced through participation cannot be expected to realistically depict the physical flood risk system, and are therefore poorly placed to be used as tools for predictive or detailed appraisal tasks. They do however, provide a means of accounting for the tacit knowledge that exists in the community, facilitating stakeholders with collecting, considering and presenting their views, priorities, and concerns. It is critical that the success of a participation process be measured not by the accuracy of the models that it produces, but in the substantial social gains it offers the community that takes part. These are reported in the evaluation sections of both cases studies (Paper II, Section 7, pII—30; Paper III, Section 7, pIII—31), and includes: bringing together diffuse tacit knowledge; building consensus and community support for preferred options; softening of extreme or unbalanced views; broadening and publicising local support networks; and facilitating social interaction between individuals affected by flooding. The usefulness of models and other outcomes exists in providing stakeholders with a mechanism through which they can record and present their collective views, and permit, through their accessibility, a wider range of local stakeholders to engage in their creation.

7.5 Future directions

Several possible directions for future research emerge from the findings of this thesis. Most of these centre on the continued use of participatory modelling techniques within the field of flood risk management, such that a clearer picture of their effectiveness arises. Understanding the benefits that different techniques offer, and what is desired from participation at different stages in the flood risk decision-making process is key to supporting process managers with choosing the most appropriate technique for a given application. Careful evaluation of participatory processes can provide the evidence required to iteratively refine and develop the frameworks outlined in this thesis (Figure 7.1).

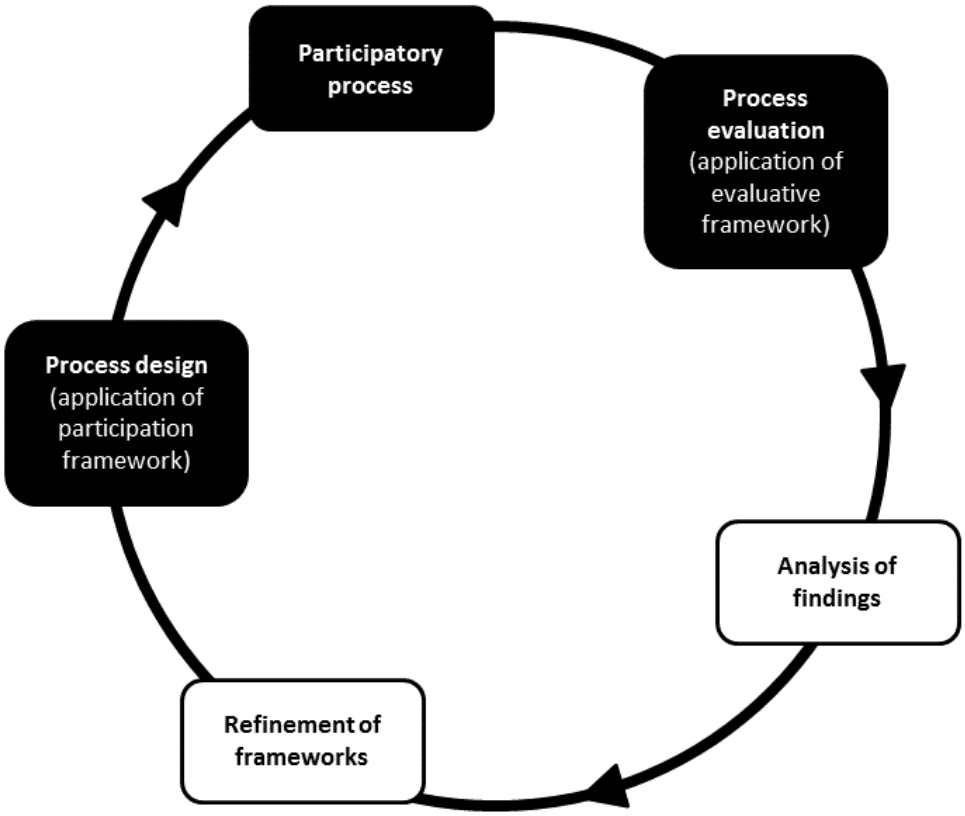


Figure 7.1 Process of ongoing learning

Supporting the above process suggests three future directions for research.

1. Application of the participation framework to future case studies

The usefulness of the participation framework as a tool to support process managers with choosing the most appropriate technique for a given context (and stage in the decision-making process) can only be assessed if the framework is applied to future participatory processes at the point of process design. Obtaining feedback from those using the framework is key to updating it.

2. Application of the evaluative framework to future case studies

Consistent application of the evaluative framework to future case studies will facilitate the ongoing improvement of the framework, and its usefulness as a tool to support process managers with reviewing the effectiveness of participation in flood risk management. It will further allow comparison between different contexts provided that the same criteria have been employed.

3. Refinement of both frameworks following analysis of their application

Careful and considered evaluation of participatory processes can provide the evidence needed to iteratively refine the frameworks such that they more fully meet the needs of process managers. Future developments to the participation framework could include the inclusion of a greater number of technique reviews; improvements in the metrics used to judge technique efficacy; refinements to the stages in the flood risk decision-making processes; and emerging 'best practice' guidance for using participatory modelling tools in flood risk management. Future developments to the evaluative framework could include changes to the evaluation criteria; the context-dependent weighting of certain criteria; and a revisiting of previous case study sites to assess whether the social outcome criteria can adequately assess the capacity for social change.

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Appendices

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Appendix 1: Preliminary interview script for Hebden Bridge

Aim

The aim of the preliminary stakeholder interview is to inform and develop the initial project objectives so that prior to the first participatory session they reflect the wide range of views and aspirations among local stakeholders.

Objectives

- To ascertain stakeholder views on the pilot objectives
- To ascertain stakeholder views on the range of catchment objectives
- To identify any other objectives they think are important
- To comment on how they think these management objectives can be achieved

Design and rationale

The interview will be semi-structured, following the guide questions below. There is scope for the interviewee to make lengthy comments as the questions are open. Questions may be missed out or covered only briefly, if the ground has already been covered in an earlier question. Interviews should last no more than an hour and be recorded. A transcript of the interview will be made afterwards, for the purposes of ensuring that the aim is met. The transcripts will not be formally analysed.

Key questions

1. What do you hope will be achieved by taking part in this project?

This is a scene-setting question to better get to know the stakeholder and the organisation that they represent.

2. Please provide any initial comments on the pilot objectives

Pilot objectives

- To bring together a range of stakeholders to discuss issues that affect flood risk in the catchment
- To model our understanding of how the catchment system works, using the best available data, local knowledge and expert opinion
- To test a novel (in the sense that it has not yet been applied to flood risk management) approach to participatory modelling

In this question, stakeholders are better informed as to the pilot objectives, and can comment on what they feel the pilot has the scope to achieve.

3. Please comment on the catchment objectives, in turn.

Initial catchment objectives

- To slow surface runoff and increasing interception rates
- To store and slowly release excess stormwater from appropriate areas
- To restore degraded upland areas, and reduce associated sedimentation
- To improve land management practices
- To better manage the flow of stormwater on paths and tracks
- To adopt water-sensitive approaches to construction and development, which offers multiple benefits beyond those of reducing flood risk
- To understand the role of the reservoirs
- To make residents aware of what they can personally do to prepare for flooding
- To make residents aware of what they can do to promote a speedier recovery

In this question the stakeholders are asked to comment on the current list of catchment objectives, which are updated following each interview.

4. Are there any catchment objectives that you consider particularly important to you/your organisation?

This will help us to identify whether the stakeholders' personal views match those of the organisation whom they represent. It will help us to identify whether any organisational views are underrepresented or missing.

5. Are there any areas that you feel are underrepresented, or that we have missed?
6. Are there any additional objectives you would like to see included and can you explain why you feel that these additional objectives are important?
7. For each of the catchment objectives, can you comment on how they might be achieved in the Hebden Water catchment?

The aim is for this to provide me with background information on the stakeholders' understanding of processes and interventions (including cause and effect) in the catchment. It will provide information to support the construction of the preliminary Bayesian networks in the initial sessions.

Close of interview

The interview will close with a discussion about times and dates when the stakeholder is free for attending the participatory workshops. At this point, it is also suggested that the stakeholder be provided with a printed copy of the pilot methodology, and is invited to discuss any points arising from it.

Outcomes

- Refined list of project objectives
- Recording of the interview

Appendix 2: Practitioner interview script for Hebden Bridge

Aim

- To derive criteria against which to assess the substantive outcomes of the participatory process (e.g. models, decisions, recommendations, knowledge, etc…)
- To assess the outcomes of this project against those criteria

Introduction

General – <u>any</u> participatory process

Q1 What are the benefits of participatory projects over those with less participation?

Q2 What are the limitations of participatory projects over those with less participation?

Q3 What would you say makes a good participatory process?

Q4 How do you know when a participatory process has been a success?

Questions

Outcomes – <u>this</u> participatory process

We are interested in finding out how practitioners assess the strength of a participatory process, particularly with regard to the short term substantive outcomes it produces.

Q5 What motivated you to participate in this project?

Q6 When you joined the process, what did you expect it would achieve? (What were your goals?)

Q7 [related] what did you expect would be the main outcomes of the process?

Outcome 1 …….

Outcome 2 …….

Outcome 3 …….

Q8 Did the project produce any surprises or outcomes you did not expect?

Unexpected, additional, long-term or non-tangible outcomes:

……

……

We will now look more closely at how you judged the success or failure of each outcome. For each outcome, we will draw up a list of (up to three) criteria which we will then use to evaluate them. Each time we evaluate we will score the criteria from 1 (not achieved) to 10 (completely achieved).

Q9 How would you know that [outcome 1] …… had been successful? (three criteria)

Q10 Can you rate this process against each of these criteria?

1. …….. 1 2 3 4 5 6 7 8 9 10
2. …….. 1 2 3 4 5 6 7 8 9 10
3. …….. 1 2 3 4 5 6 7 8 9 10

Q11 How would you know that [outcome 2] …… had been successful? (three criteria)

Q12 Can you rate this process against each of these criteria?

1. …….. 1 2 3 4 5 6 7 8 9 10
2. …….. 1 2 3 4 5 6 7 8 9 10
3. …….. 1 2 3 4 5 6 7 8 9 10

Q13 How would you know that [outcome 3] …… had been successful? (three criteria)

Q14 Can you rate this process against each of these criteria?

1. …….. 1 2 3 4 5 6 7 8 9 10
2. …….. 1 2 3 4 5 6 7 8 9 10
3. …….. 1 2 3 4 5 6 7 8 9 10

Thank you for taking part in this interview.

Appendix 3: Post-project interview codebook for Hebden Bridge

In vivo codes from the post-project interview transcripts are collated and organised according to the evaluation criteria outlined in Paper II, Section 7.

Process Criteria

In vivo code	Analytic codes
Participatory activities, resources and language were designed such that all participants could fully engage, regardless of skills and experience <u>Technique (BN) accessibility</u> Fundamental concepts were understood Understood it at the time No prior knowledge or experience needed Model is useful Model can be understood by stakeholders Model would be good educational tool Understand the concept of how the model works Software user-friendly and does most of the work for you* Praise for the method, accessible to participants Method was accessible to participants Difficult to use the model without the research team* Model needs to be more user-friendly Process and model were accessible to a non-expert Need additional resources to continue to use the model* The model doesn't need to be fully understood to find the process useful* Found model confusing Process is confusing – but that is OK! Process was accessible (x2) <u>Others</u> Need a simpler way of refining and viewing the collected information Need a simpler way of communicating information (x2) A lot to take in Correct pitch Participants worked effectively through the process Need to be careful with use of terminology (x2) Communication of interconnectivity depends on how user-friendly the outputs are Unsure how the results could be communicated to the general public	Accessibility

Project was visual and graphical Need a way of tracking and recording changes (x2) Need for a tool which can be used without reliance on expert input Found model too academic Model was too academic Value was in the making of the model, not using it Did not like the model – found it too academic Model was good to look at **Clear and frequent communication kept the modelling process transparent** Stakeholder communications (e-bulletins) were good Need more information for participants to take away from workshops Good stakeholder communications Stakeholder communications between workshops were good	
Participatory activities fostered knowledge exchange, debate and consensus building <u>Knowledge exchange</u> Imparting knowledge Learnt about different opinions Sharing of information Value in the process of building the model, especially discussions* Stakeholders got opportunity to hear what others thought Appreciating others' points of view Learning from other stakeholders Appreciating and understanding different stakeholders' views Sharing of ideas Useful to hear different viewpoints Listening to other people's views Participants shared views and listened to others <u>Debate (and discussion)</u> Getting together (x2) Exposed to different opinions Getting people's views together (x2) Observing the range of different views in the community (x2) Improved understanding of different people's views Process more about discussion and debate than accepting others' viewpoints* Discussions as valuable as the outcomes Opportunity to talk with other stakeholders Good discussion generated Useful to meet and talk to other stakeholders	Deliberation

Initiated conversations Conversations were useful Generated interesting debates (x3) Usefulness was in the creation of the model, and the discussions that generated* Stakeholders openly discussed issues <u>Consensus</u> Consensus reached – but may be due to skewed group Participants moved towards consensus A small move is quite good in this sector Participants agreed on the interconnectivity and the limited impact of individual schemes Group moved towards consensus(x2) Reaching consensus Process started to build consensus Reaching consensus Process brought people closer to consensus (x2) Softening extreme views* Agreement was reached by those that stayed to the end* <u>Others</u> Unsure whether stakeholders' opinions were changed A process that can bring people with you Educative value of process Process is educational Process was educational Enables views to be quantified People were open with each other Model as an educative tool	
The participants are representative of the affected community and the full range of views Biased towards the opinions of those that created the model Group was not total representative Group lacked the 'neutral' people Group were not representative of the community The group membership was such that it already favoured community stewardship (x3) Especially the EA Although residents were recruited, the group that stuck with the process were stakeholders Importance of recruiting an unbiased group* Needs political buy-in to get out to a wider audience Need to get political representation Need to upscale the process – get more people involved Need to recruit those affected by flooding	Representation

Social demographics of Hebden Bridge created a tolerant group Model represents views of a small number of people People dropped out Not enough non-specialists towards the end Group lacked members of the dredging community or they dropped out Dredgers possibly felt they weren't being heard Need more people involved for entire process **All participants were given opportunity to make a substantive contribution** Involvement in decision making Opportunity to express and share opinions Involving people in decision-making Open discussion, people can openly disagree Found the opportunity to share views and knowledge with the group Care taken not to impose views when seen as an 'expert figure' Process puts everyone on an equal standing Process empowers as participants are all equal Participants more reserved in whole-group discussions Experts and non-experts are seen as equals People get to have a say in technical issues Sharing of responsibility Value of open discussion without apportioning blame Was able to share understanding with other participants	
Participatory tools were chosen according to local objectives, resources and available data Using opinions to create a better model Model useful for capturing complexities, especially opinions and different management options* Model is based on assumptions/beliefs Need to challenge those assumptions as a whole group Interventions were quite general (x2) Concerns over the share of inputs which were people's opinions Interventions in the model could be more specific* Identifying key variables using local knowledge* Model did not represent some issues fully Model was specific to the conditions in the Hebden Bridge area* Model relevant to local conditions **The participatory process was flexible to change, with the agenda and activities shaped by the needs and goals of the participants** Process is very holistic – unsure whether this is good or bad Process could be quicker Can see own input in model*	Responsiveness

In other areas compromises have been made Value of taking into account local knowledge in existing ways of working Modelling environment allowed testing of scenarios Limited in scope and range of inputs <u>Comments on method awareness</u> New approach Knowing what tools are available (x2) Learning about modelling capabilities Learning about the available tools and software Introduced to the method Awareness of method Knowing that the tools exist and being introduced to them Awareness of the tools that exist Awareness of the tools that exist	
Participatory activities were facilitated in a professional and effective manner Fundamental concepts were understood Pace good Well-structured (tasks) Group size was too small, especially for breaking into smaller groups Although an expert, still got something out of attending* Participants worked well together and helped each other Time between workshops allowed individual learning Importance of having a skilled facilitator Gives thinking time between workshops Thinking time given **The participants knew what was expected of them and what they could expect to gain from participating** Time demands were reasonable Better introduction needed to the methodology (x2) Participants need to commit to 2/3 of the programme to get something out of it (x2) Participants relaxed into the project Process requires an attendance commitment Process required a large time input Difficult when stakeholders drop in and out of the process Length of process was appropriate Longer process enables bringing everyone up to the same level Group found using the model was worthwhile Some stakeholders dropped in and out Length and timings of project were appropriate	Satisfaction

Challenge of coming late into the process Participants need to commit to the whole process **The process had clear purpose, objectives and direction** Good first step Well-structured (process) Useful early addition to the process Model useful in the earlier stages of a flood risk modelling process Involving stakeholders earlier in the process – in generating options No problems with length and pace Over time, the process became clearer Project should not be longer – possibly shortened or condense Structure allowed stakeholders to contribute, and work together on a problem Outcomes were not always concrete Model use became clearer over time Need to see how it will work in practice Useful starting point Structure helped to make process logical <u>Comments on length of process</u> Necessary to have so many workshops Workshops need to be closer together Process would need to be quicker if done commercially More regular meetings More meetings useful, but fatigue and drop-outs would increase Process was long Would condense into day-long workshops (x2) Lengthy process was required Length appropriate	

Evaluation of substantive outcomes

In vivo code	Analytic code
Model is accessible/available Model as a product Model as an educational tool Use and accessibility of model Model as an educational tool Accessibility to new users Model as an educational tool (x2) * Software is generally easy to use	Model

Model needs supporting documents to be more accessible * Software is generally easy to use Difficult to understand some concepts (in particular process limitations) * **Model continues to be used** Transferability (as a tool) (x2) * Sharing model with people outside of participatory group (x2) * Model use Using model beyond participatory group *	
Flooding is seen as a complex issue with multiple solutions Improving knowledge base – challenging misconceptions Awareness of complexity (of issue and solution) (x3) * Complexity of issue Identifying areas to explore further Improving awareness Lots of people with different approaches formed one group Presented complexity of flooding issue Understanding complexity of flooding helps to understand other issues Complexity of flooding issue Process education value Complexity of flooding issue, need for multiple solutions Views are openly and honestly considered Awareness of flooding and potential solutions * Increased knowledge of flood risk People are generally better informed about flooding (x2) * **Residents understand how to reduce own flood risk** Groups/individuals understand their influence Model showed various things an individual could do to reduce their own flood risk * People have different levels of understanding – problem if them attend sporadically People have sufficient knowledge and information to feel able to take action Awareness of flooding, especially personal flood resilience Generation of ideas (small-scale solutions) to manage personal flood risk * Unsure of impact on flood risk awareness **Highlighting community priorities** Highlighting community priorities * Using results for agenda setting Suited for use early in the flood management process – when strategic thinking is important * Use immediately after flood events Finding out what the general public were thinking	Understanding

General public has realistic expectations of agencies Clearly defined roles Groups understand their role Identifying expectations – what do public expect of EA Reputation, way EA is viewed by community Setting goals and realistic, clear expectations - at the outset Setting goals and realistic, clear expectations - at the outset Realistic expectations (of the EA) and of what can be achieved* Hard to measure whether expectations have changed Set realistic expectations of what the EA can influence/achieve * Can raise expectations (negative) Initial separation between agency staff (EA/Council) and residents A good process gives realistic control and expectations Understanding (managing?) public expectations of EA and Council Not sure whether people have realistic expectations * **Residents understand they have a personal responsibility** Participation processes need to demonstrate shared responsibility for flooding * Aligns with a national move towards participation Community empowerment Need to look at issue as a community Surprise that participants were still interested in solutions that would only have a small effect * Level of support and unity *	Responsibility
Reducing flood risk remains a priority in the community Lasting community support of projects Better communication as a result Flooding not so much of a community priority now * Participation as a driver of social change Interest in flood risk maintained several years after event * Flooding is back to being a priority * **Participation is increased and/or maintained** Community buy-in Transparency Representative group (x2) Dissemination of findings Community has to want to participate (x2) Different levels of participation Importance of core people that will stay with the process through its entirety Clear process structure: goals, endpoints, outcomes (x2)	Action

Flexibility within a project Seeing where a process fits into the bigger picture (x2) Process needs to be short and engaging Satisfaction Satisfaction Impact on public participation small compared to effect of flooding event Issue of the usual suspects attending – may put others off Wide representation Clear vision Setting clear goals and milestones; and recognising achievement of them Generates discussion (x2) Setting realistic goals People need a clear idea of why they are there Needs to be value added (x2) Participants bought into the process * Process took participation to a higher level * Feedback positive * **Individual action (change in behaviour)** To get buy-in you need the right group to participate Change in behaviour Change in behaviour shows influence Change in behaviour shows a gaining of knowledge * Hard to judge impact on flood resilience * Unsure whether PLP has increased (x2) * Slight increase in PLP adoption * **Community action (including volunteer action)** Action as a result Existing groups/individuals are open to new ideas – and put these into action – as a result of what they have learnt * Using new knowledge Innovative solutions * Volunteer energy comes from seeing benefits of actions * Volunteer participation is higher in Hebden Bridge than in surrounding areas * People are looking at multiple benefits, including effect on flooding *	

An asterisk (*) indicates respondent was referring to the Hebden Bridge process

Evaluation of social outcomes

In vivo code	Analytic code
Participants shared in the coproduction of knowledge on local flood risks (including hazard, exposure and vulnerability) Information capture Using opinions to create a better model Sharing of information Process more about discussion and debate than accepting others' viewpoints Learning from other stakeholders Learning from other stakeholders Structure allowed stakeholders to contribute, and work together on a problem Identifying key variables using local knowledge Process as way of educating the community Awareness that local knowledge is essential in models* Increasing community knowledge and understanding Meeting and discussing flood risk with expert stakeholders (EA) (x2) Usefulness was in the creation of the model, and the discussions that generated **Participants discussed their perceptions of risk, and explored a range of interventions that could mitigate them** Thinking about flood risk* Open discussion, people can openly disagree Model covered lots of different elements of flood risk* Value in the process of building the model, especially discussions Involving stakeholders earlier in the process – in generating options* Particular potential for thinking up alternatives to the traditional flood alleviation scheme* Participants agreed on the interconnectivity and the limited impact of individual schemes* Created a clearer mental map* Understanding multiple risks and their management* Group was skewed towards interventions in the uplands Was able to share understanding with other participants* Model allowed exploration of different interventions* Model looks beyond the usual interventions* Useful opportunity to talk with experts* *<u>Looking at the system in a holistic way</u>* Putting everything together Required participants to think holistically* (x2) Process improved understanding of how issues are connected Thinking about system holistically was a strength Understanding the solutions holistically	Knowledge

Holistic view Necessary to view the issues holistically Project enabled exploration of feedbacks Encouraged holistic thinking Need to view the system holistically Importance of studying different elements of the system, then bringing them together* Looking at connections Understanding how system elements are connected **Participants know who to go to for support within and outside of the community, and feel better prepared for another flood event** Getting to know who the other stakeholders are Useful to meet other stakeholders Networking Networking Understanding different stakeholders' roles Promotion of engagement between professionals and non-professionals Useful opportunity to talk with experts* Useful to meet and talk to other stakeholders Opportunity to talk to experts in the field	
Participants feel motivated to take ownership and responsibility for taking a proactive role in the reduction of local flood risk Involvement in decision-making Involving people in decision-making* Process empowers as participants are all equal* Everyone is responsible for understanding flood risk – led by the agencies The group were particularly well suited to this kind of working (x2) Empowers local members of the public to get involved* Local people develop knowledge to be able to hold public bodies to account* (x2) Stakeholders want to be more engaged Sharing of responsibility Flood resilience came through as a strong theme* Individuals have some responsibility Responsibility for managing flood risk is shared Everyone has a responsibility for informing themselves about flood risk **Participants identified a range of appropriate interventions that could be implemented by either individuals and/or the community** Model useful for capturing complexities, especially opinions and different management options* Participants agreed on the interconnectivity and the limited impact of individual schemes* Developed understanding of the complexity of managing flooding – no single solution*	Motivation

Value of taking into account local knowledge in existing ways of working Process encourages thinking beyond the usual interventions* Involving stakeholders earlier in the process – in generating options* Particular potential for thinking up alternatives to the traditional flood alleviation scheme* Flood risk management is more than just stopping flooding Managing flood consequences and people's expectations Model looks beyond the usual interventions*	
Relationships were developed between participants and organisations both within and outside of the local flood risk community Getting together (x2) Networking Networking Understanding different stakeholders' roles Improving stakeholder relationships* Understanding group politics Promotion of engagement between professionals and non-professionals. Especially the EA Useful in getting organisations working together Powerful way of getting organisations to work together Useful way of getting local flood risk stakeholders working together Meeting other stakeholders Conversations were useful Meeting and discussing flood risk with expert stakeholders (EA) (x2) Most stakeholders already knew each other Working in teams **Trust was improved between participants from both within and outside of the local flood risk community** Process puts everyone on an equal standing Process empowers as participants are all equal* Single engagement events can be damaging and ineffective Experts and non-experts are seen as equals Value of open discussion without apportioning blame* Group were ready to listen to evidence even if it disagreed with what they felt* Enabled appreciation of different people's opinions Process allows experts and non-experts to work together as equals Working with experts helped participants engage with ideas* People were open with each other	Networking

Evaluation of context criteria

In vivo code	Analytic code
The scientific and technical aspects of the problem are understood Experts don't know everything **The risks of flooding are understood** Increasing the understanding of flood risk in the community is essential* The press need a better understanding of flood risk	Understanding
There is a clear structure of roles, responsibilities and competencies Responsibility lies with agencies (x2) Individuals have a responsibility to manage flood risk Primarily the EA and Local Authority Everyone has a responsibility People will need support from the EA (x2) EA taking the lead EA role one of understanding flooding EA and Local Authority 'own' the flood issue Traditional view is to let the technical experts manage flood risk Local authorities struggling with the responsibilities placed on them by the Pitt Review* Role of DEFRA EA, Local Authorities and DEFRA have an obligation to increase understanding of flood risk EA and Local Authorities need to take the lead on managing flood risk Everyone is responsible for understanding flood risk – led by the agencies Prime responsibility lies with the Local Authority, EA and DEFRA Responsibilities not always clear to members of the public* EA and Local Authorities are responsible for communicating understanding of flood risk Everyone has a responsibility for informing themselves about flood risk Responsibility of managing flood risk is with EA and Local Authority Understanding flood risk is responsibility of all Agencies are responsible for educating the public Responsibility lies with the EA **Managers have confidence in the participatory process** Some groups unsure of involving the public in flood risk planning Sharing the responsibility of decision-making Single engagement events can be damaging and ineffective Local people may not be responsible for managing flood risk but need to be respond to it EA are wrongly seen as the only experts Process gives local stakeholders a more equal footing Need to be doing public engagement differently Managing the outcomes could be more challenging than the process Cuts in the EA could make lengthy engagement processes difficult in the future	Support

Risk of solving problems solely in established ways **Participants have confidence in those managing the process** Understanding of flood risk comes from experts tasked with modelling* (x2) Community action needs to be supported by expert advice and analysis* Faith in expert computer modelling If participatory processes can engage with the 'loudest voices' then time and money can be saved	
Pre-existing relationships are positive Group worked well together The group were particularly well-suited to this kind of working (x2) Stakeholders worked well as a team Stakeholders supported each other with use of technology Most stakeholders already knew each other **Stakeholders' goals/views are similar** Participants voice strong opinions Some stakeholders voiced strong opinions Stakeholders held opposing views Some stakeholders came with biases Polarised views may resurface when an action plan is produced Stakeholder opinions differed, but these were worked through Some stakeholders had preconceived views Stakeholders had different ideas, but put these aside to work on the model* Some groups may have been unable to accept others' viewpoints **Participants care about the issue/problem** Stakeholders had a common interest The social backgrounds of the participants allowed the process to run more smoothly than it might do elsewhere The group were particularly well-suited to this kind of working (x2) A community has to 'want to learn' to get something out of the process Stakeholders want to be more engaged Social demographics of Hebden Bridge created a tolerant group	History
The problem is simple Participants agreed on the interconnectivity and the limited impact of individual schemes* **A small number of agencies are responsible for the issue/problem** Responsibilities not always clear to members of the public* Responsibility for managing flood risk is shared	Complexity

Responsibility is shared (x2) **The geographical extent is clearly defined and manageable** NO CODES **There is consensus on how the issue should be managed** Group was skewed towards interventions in the uplands The group membership was such that it already favoured community stewardship (x3)	

Other themes

In vivo code	Analytic code
Cost-effectiveness Need to understand the benefits so they can be weighed up against the costs and time input required Resource cuts in the EA and Local Authorities make catchment-scale management challenging Difficult to evaluate the benefits of this kind of engagement	
Politics Needs political buy-in to get out to a wider audience Need to get political representation Taking the project further through the National Flood Forum Reducing the consequences of flooding needs wider recognition in government to justify funding	
Future Potential for publicity as national example of good practice	

Appendix 4: Preliminary interview script for Southwell

The interview script is split into three parts, each one up to fifteen minutes in length. Part one is an open discussion, part two consists of several semi-structured questions, and part three is a structured survey.

Part One – Defining the Problem

Aim

To compile a list of key problems surrounding the managing flood risk in Southwell

As interviews are completed, a list of key problems will be developed that can be refined after each new interview. Early interviews will start to form this list.

Initial question

What would you say were the three most concerning flood risk problems facing Southwell?

Note: these can be things that cause floods to be more likely, or cause floods to have greater consequences when they occur. These two factors make up what is commonly called "flood risk". Examples:

"The public do not know what to do when flooding occurs"

"People do not know how to protect their homes from flooding"

"There is nowhere for stormwater to go once the drains are full"

"There is not enough help to recovery quickly from flooding"

"Drains and watercourses are regularly blocked for long periods of time"

"It is unclear who/where to go to for information"

"Flood warnings do not get through, or are unclear"

Follow-up (once a list is formed):

Please comment on each of these problems in turn (list will be provided).

Are there any additional issues that are particularly important to you/your organisation?

Part Two – Managing Expectations

Aim

To investigate what participants are expect from a participatory process, so that the process can be designed around their needs

Questions

- What are you hoping to learn by taking part in this process?
- What would you like to know more about?
- What are your expectations of the process?
- What are you most looking forward to?
- How do you see this project complementing other flood risk activities that are already going on?
- Have you taken part in a participatory process before?
    - If so, how did you find it?
- Is there anything you are concerned about?

Part Three – Social Capacity

Aim

- To establish a baseline of social capacity at the start of the participatory process
- This section is further split into knowledge, motivational and network capacities.

Please state how far you agree with each of the following statements, on the following scale:

1 – Strongly disagree, 2 – Disagree, 3 – Neither agree nor disagree, 4 – Agree, 5 – Strongly agree

You may answer "I don't know" to any statement.

Knowledge capacity statements

- I understand flood risk in Southwell
- I understand how flood risk is currently being managed in Southwell
- I understand how flood risk is modelled
- I have strong views about how flood risk should be managed
- I understand other people's views about flood risk
- My views are closely aligned with others in the community

- I talk about flood risk with others

Motivational capacity statements

- I am affected by flooding
- I feel able to share my views and knowledge regarding flood risk with decision-makers
- My views, knowledge and experience are valued
- It is my responsibility to understand about flood risk
- It is my responsibility to help manage flood risk
- I have a role in managing flood risk in Southwell
- I am involved in decision making regarding flood risk in Southwell

Network capacity statements

- I know who is responsible for managing flood risk
- I trust those that make decisions about flood risk
- I understand the role of the Environment Agency
- I understand the role of the Local Authority
- I know who to go to for support regarding flood risk
- I know how I can help to manage flood risk

Appendix 5: Practitioner interview script for Southwell

In the Southwell study, practitioners played an important but relatively remote role. While practitioners were involved in the study design and development, the majority of participants in the workshops were residents. With this in mind, their evaluation of the project should be undertaken rather differently.

Instead of evaluating the process and the longer term outputs that arose from it, we are interested in finding out what they as practitioners feel participatory processes (particularly in the area of flood risk) should deliver; and whether they felt this project was successful while bearing those criteria in mind.

Aims

- To derive criteria against which to assess the substantive outcomes of the participatory process (e.g. models, decisions, recommendations, knowledge, etc…)
- To assess the outcomes of this project against those criteria

Introduction

General – any participatory process

Q1 What are the **benefits of participatory projects** over those with less participation?

Q2 What are the **limitations of participatory projects** over those with less participation?

Q3 What makes a good participatory process?

Q4 How do you know when a participatory process has been a success?

Questions

Outcomes – this participatory process

We are interested in finding out how practitioners assess the strength of a participatory process, particularly with regard to the short term substantive outcomes it produces.

Q5 What were the main **strengths** of this participatory processes?

Q6 What were the main **weaknesses** of this participatory process

Q7 What you think it **delivered**?

Q8 Did the project produce any **surprises** or outcomes you did not expect?

Unexpected, additional, long-term or non-tangible outcomes:

……

……

Q9 What did you hope would be the main **outcomes** of this process? (What were your **goals**?)

We are primarily looking to identify up to three tangible outcomes (model, understanding, discussion, consensus, recommendations, prioritisation of options, identification of novel ideas, etc…).

Q9a Outcome 1 …….

- Why is this outcome **important** to you/your organisation?
- To what extent do you think the project **delivered** this outcome?
- What elements do you think it delivered **well**?
- What do you think could be **improved** to deliver this outcome?

Q9b Outcome 2 …….

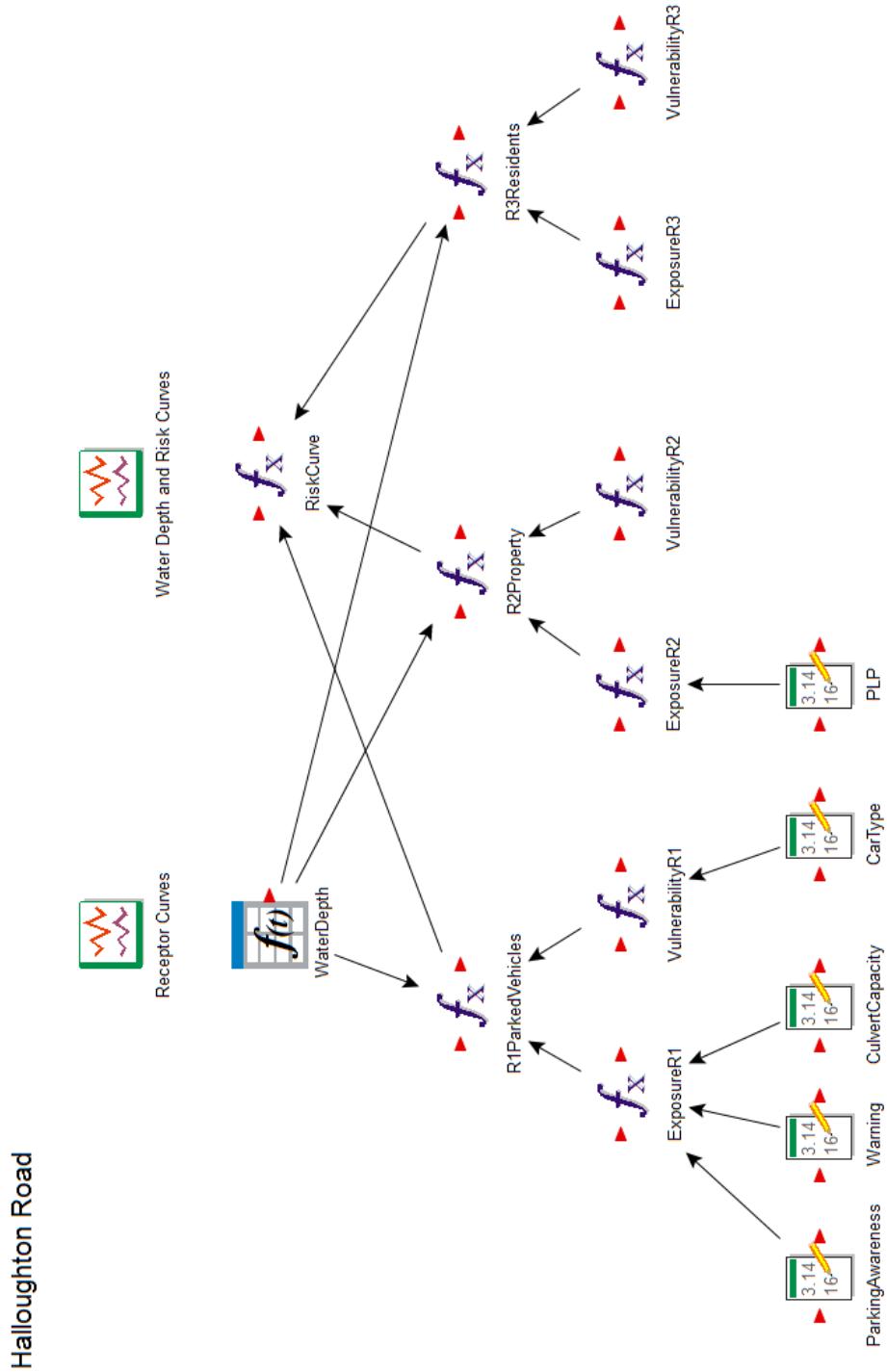
- Why is this outcome **important** to you/your organisation?
- To what extent do you think the project **delivered** this outcome?
- What elements do you think it delivered **well**?
- What do you think could be **improved** to deliver this outcome?

Q9c Outcome 3 …….

- Why is this outcome **important** to you/your organisation?
- To what extent do you think the project **delivered** this outcome?
- What elements do you think it delivered **well**?
- What do you think could be **improved** to deliver this outcome?

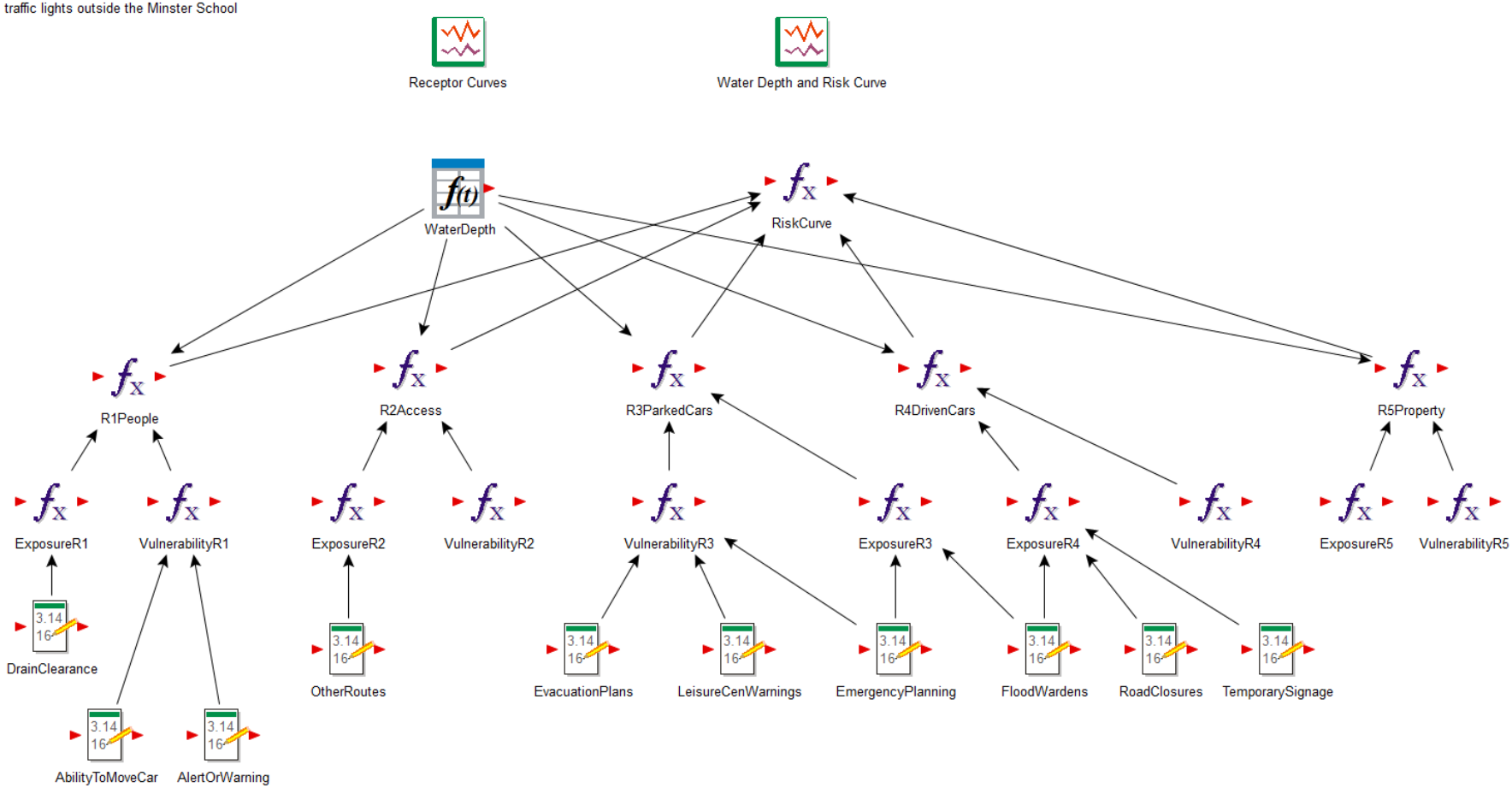
Thank you for taking part in this interview.

Appendix 6: Model diagrams



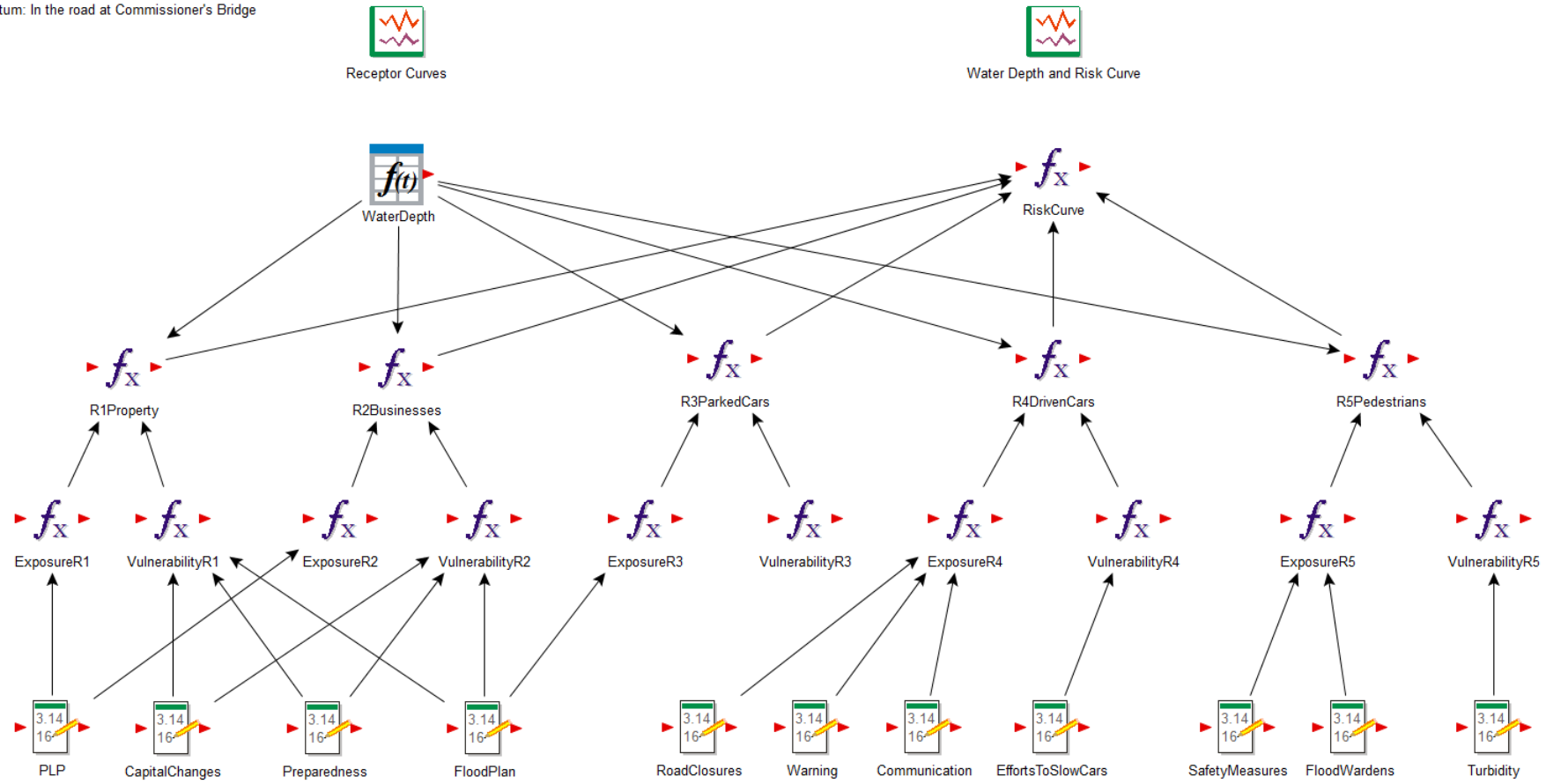
Nottingham Road

Datum: traffic lights outside the Minster School

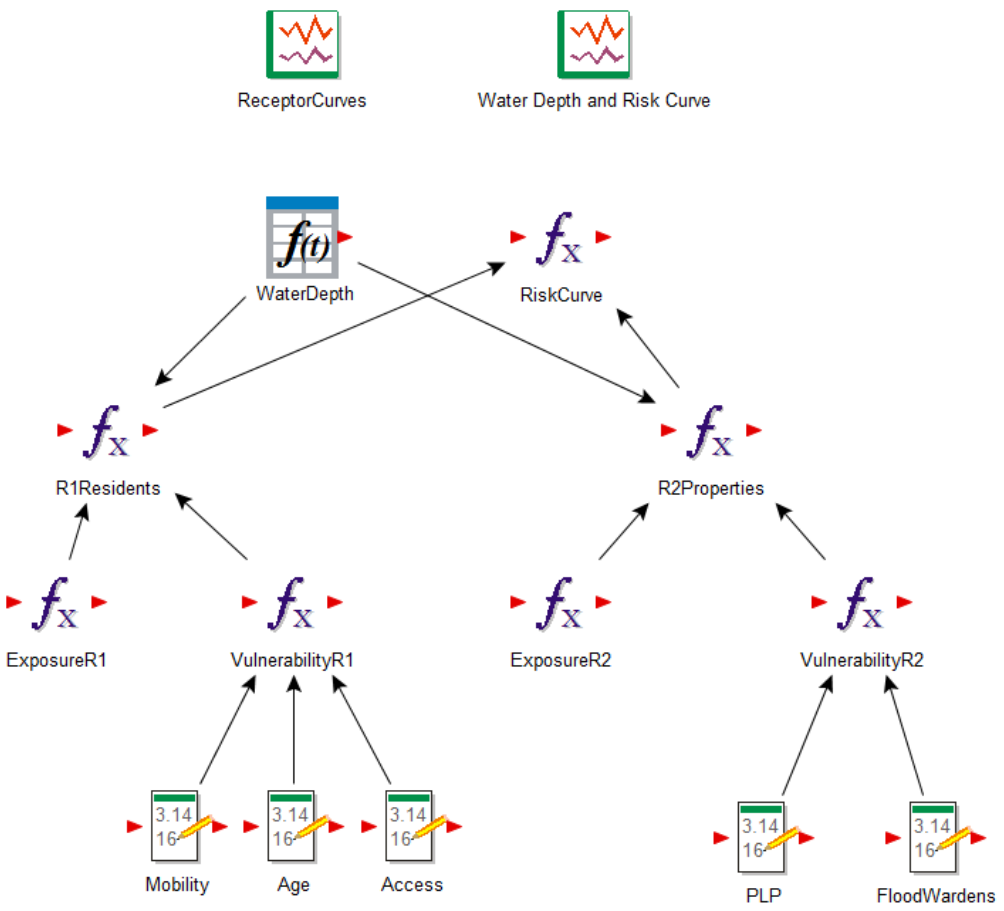


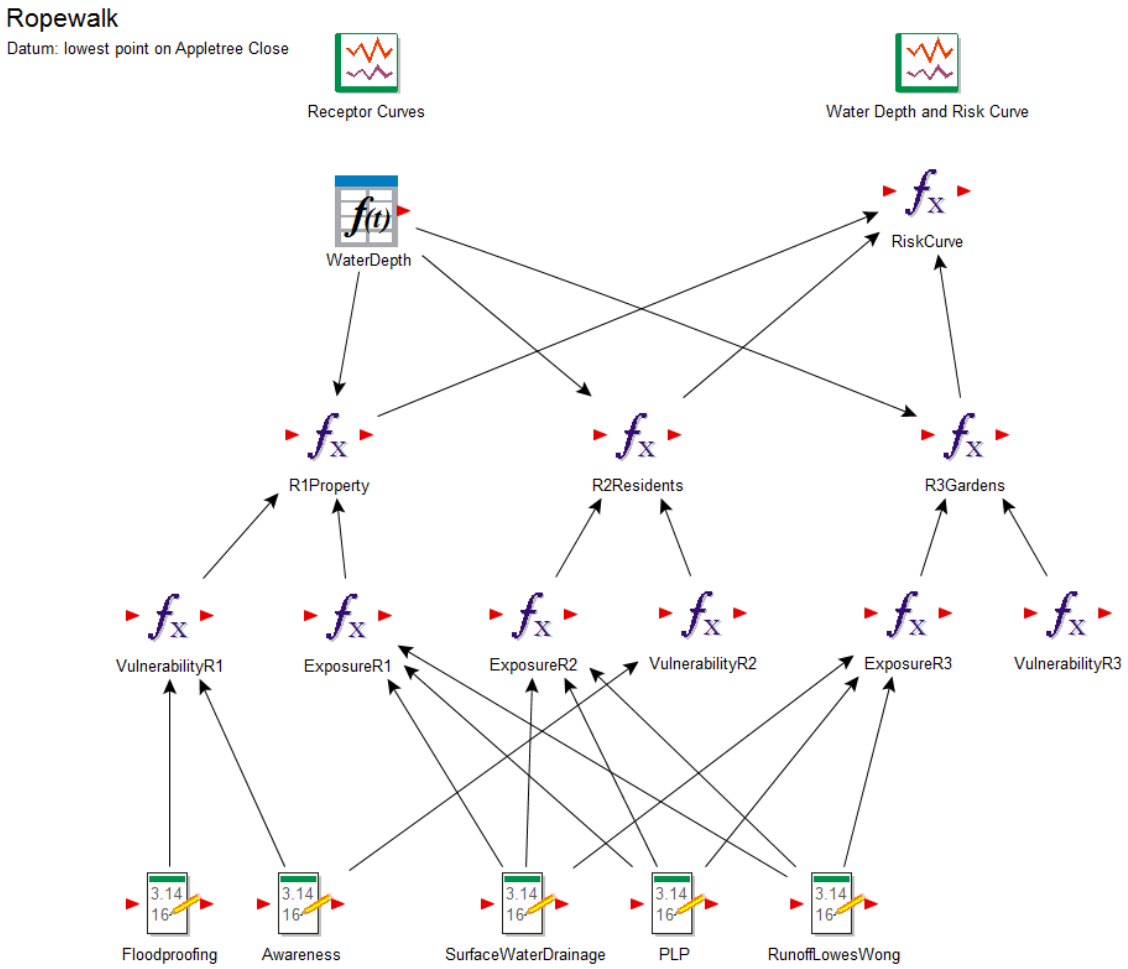
Church Street

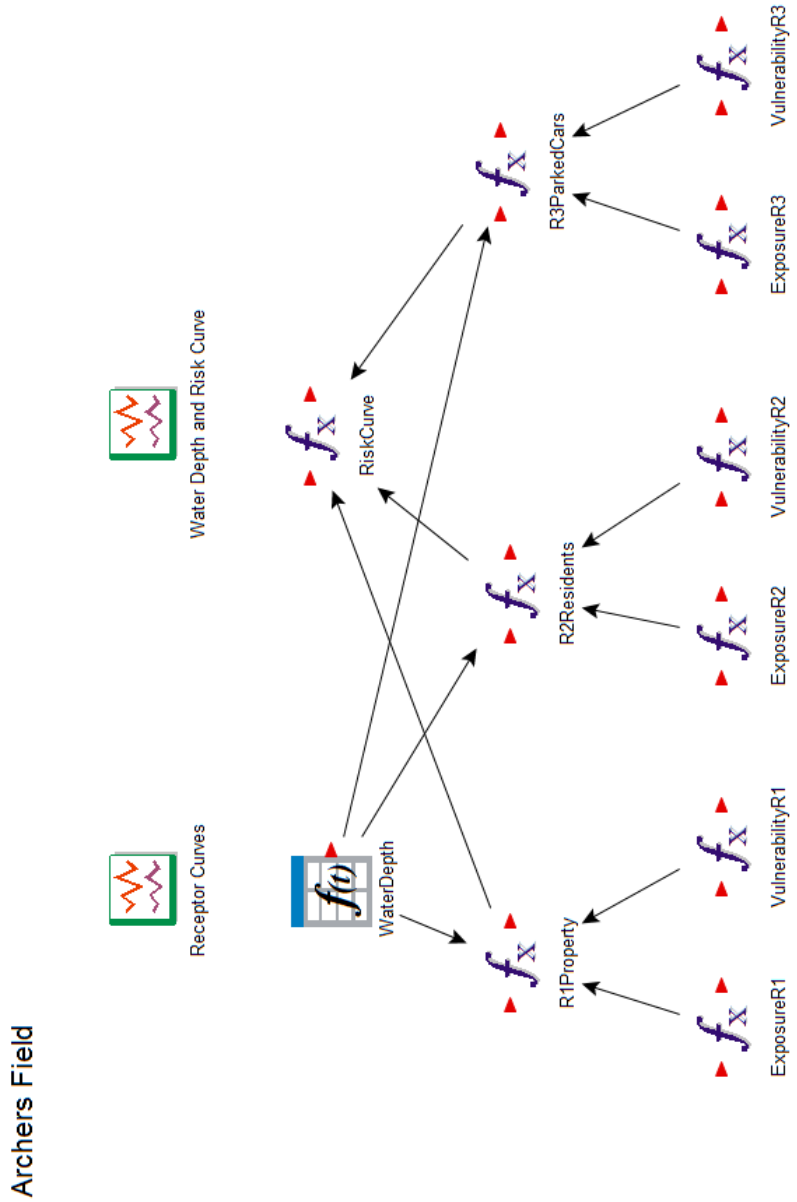
Datum: In the road at Commissioner's Bridge



Potwell Close



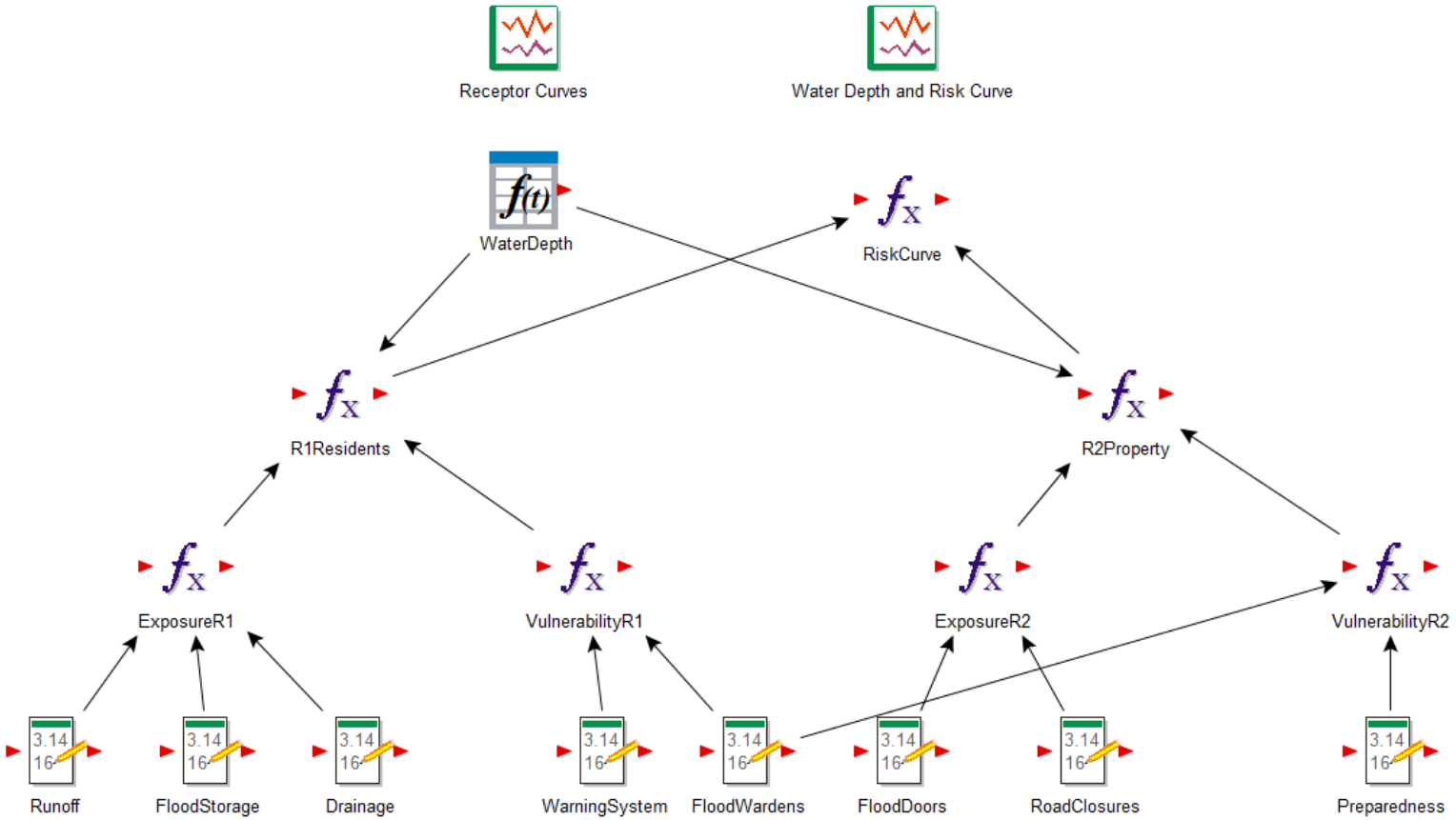

Ropewalk
Datum: lowest point on Appletree Close
Receptor Curves
Water Depth and Risk Curve
WaterDepth
RiskCurve
R1Property
R2Residents
R3Gardens
VulnerabilityR1
ExposureR1
ExposureR2
VulnerabilityR2
ExposureR3
VulnerabilityR3
Floodproofing
Awareness
SurfaceWaterDrainage
PLP
RunoffLowesWong



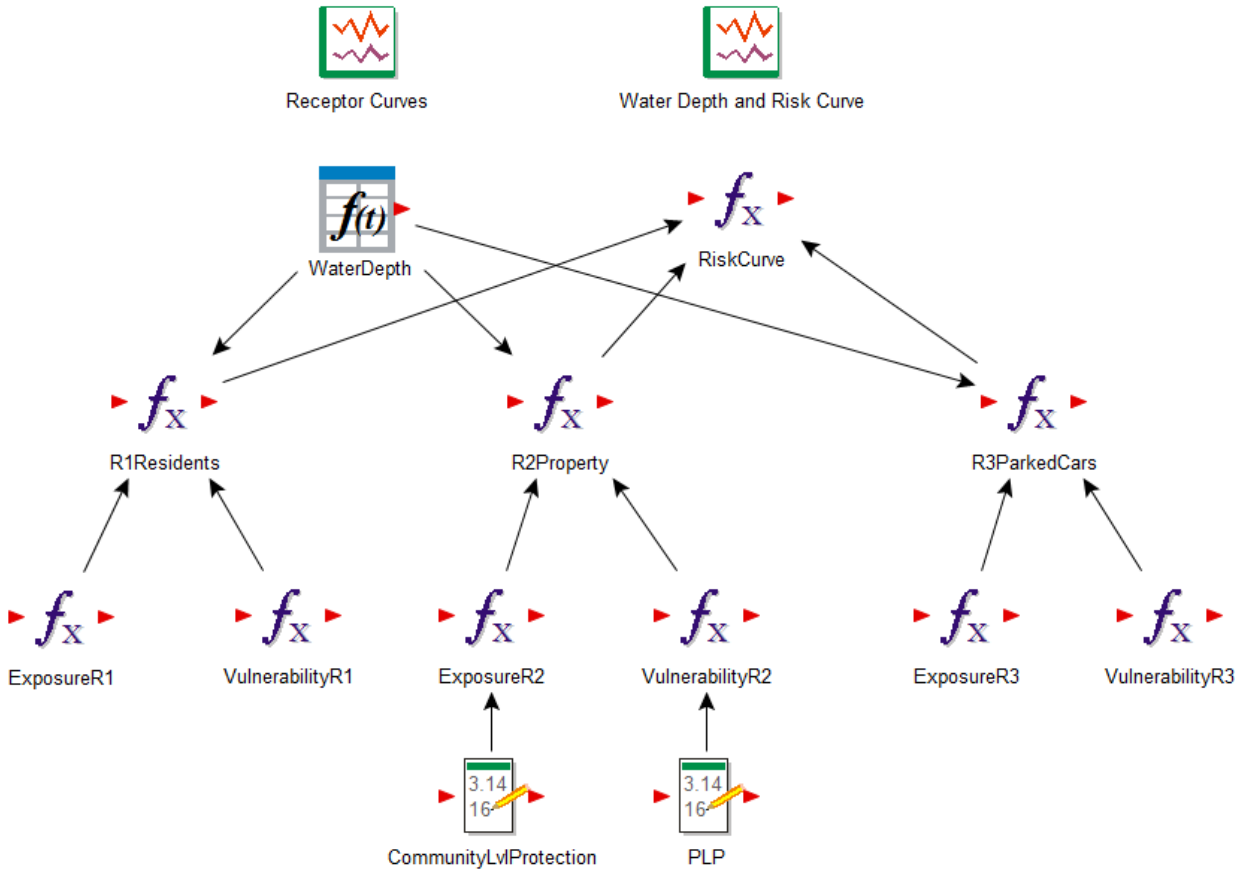
Please note that for Archers Field, no specific interventions were discussed.

Merryweather Estate

Datum: junction of Kirklington Road and Glenfields



Crafts Way

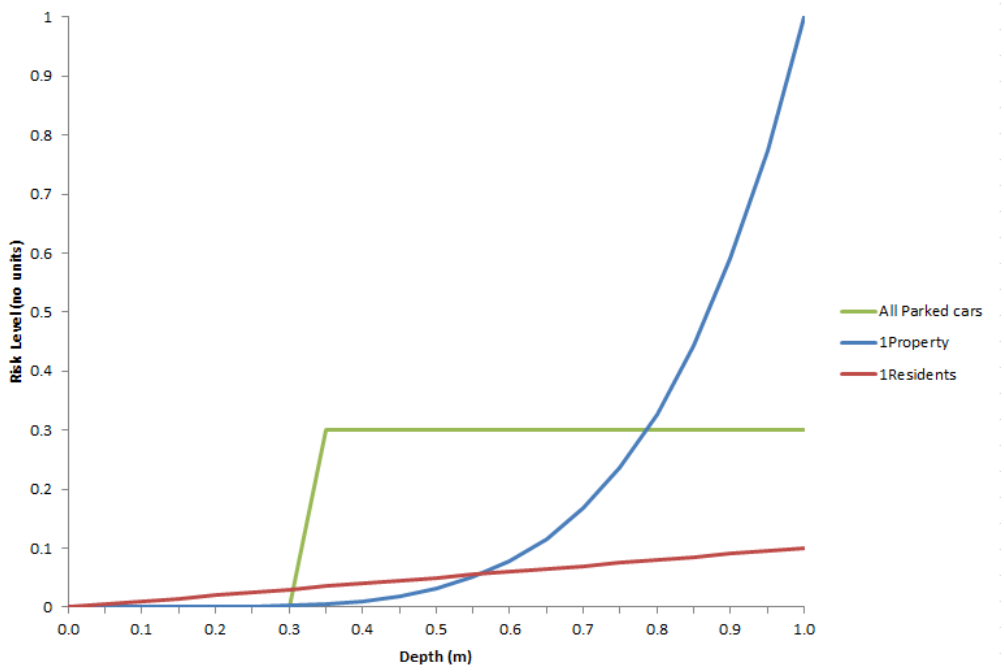

Receptor Curves
Water Depth and Risk Curve
WaterDepth
RiskCurve
R1Residents
R2Property
R3ParkedCars
ExposureR1
VulnerabilityR1
ExposureR2
VulnerabilityR2
ExposureR3
VulnerabilityR3
3.14
16
CommunityLvlProtection
3.14
16
PLP

Appendix 7: Vulnerability-depth relationships for all receptors

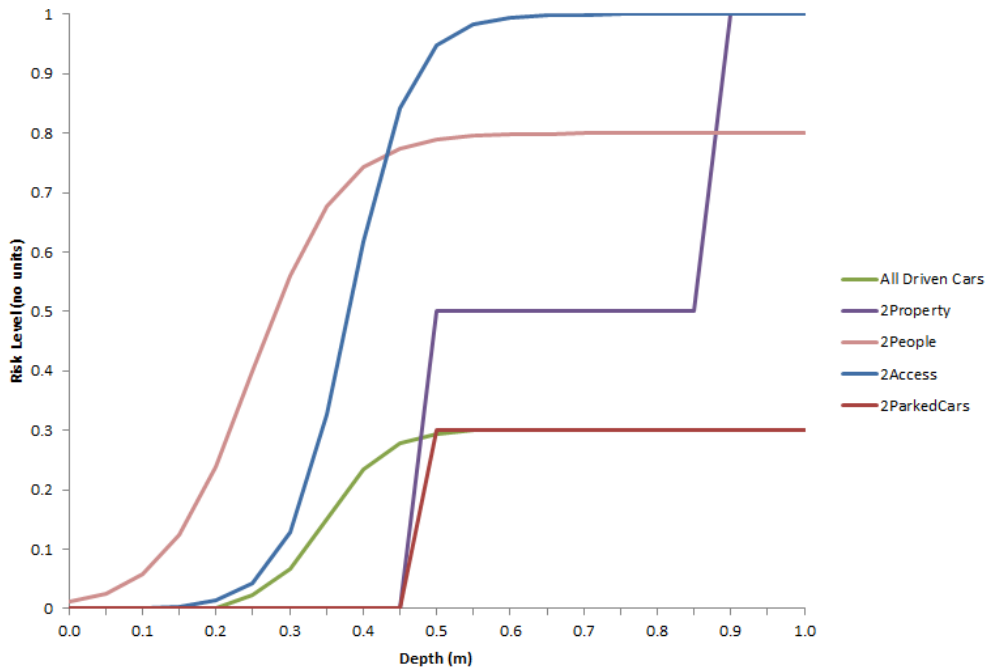
Site.Receptor	Equation	Type	Description
All.Parked Cars	IF(x>0.3,0.3,0)	Step-change	Below 0.3m risk is 0, above 0.3m risk is 0.3
All.Driven Cars	IF(x>0.5,0.3, IF(x<=0.2,0, $\frac{0.3}{1+exp^{-25(x-0.35)}}$	Nested IF, sigmoid function	Above 0.5m risk is 0.3 Below 0.2m risk is 0 Between is S-curve centred on 0.35m depth, with risk maximised at 0.3m
1.Property	x^5	Exponential increase	Risk increases slowly at first then at an exponential rate
1.Residents	$x * 0.1$	Linear	Low rate of linear increase with depth
2.People	$\frac{0.8}{1+exp^{-17(x-0.25)}}$	Sigmoid function	S-curve centred on 0.25m depth, with risk maximised at 0.8m
2.Access	$\frac{1}{1+exp^{-24(x-0.38)}}$	Sigmoid function	S-curve centred on 0.38m depth, with risk maximised at 1m
2.ParkedCars	IF(x>0.5,0.3,0)	Step-change	Below 0.5m risk is 0, above 0.5m risk is 0.3
2.Property	IF(x<0.5,0, IF(x<0.9,0.5, 1)	Two step change	Risk below 0.5m is 0, between 0.5-0.9m is 0.5, and above 0.9m is 1.
3.Property	$1(1-exp^{-6x})$	Exponential decay (increasing form)	Risk increases rapidly at first with depth then slows, reaching its maximum at 1m.
3.Businesses	As for 3.Property		
3.Pedestrians	IF(x<=0.15,0, IF(x<0.4,2.2222x-0.3333, IF(x<0.5,0.5, -0.4x+0.7)	Nested IF	No risk until 0.15m, then a steep increase until 0.4m. Stays constant until 0.5m then starts to decrease.
3.DrivenCars	IF(x>0.5,0.3, IF(x<=0.1,0, $\frac{0.3}{1+exp^{-25(x-0.25)}}$	Nested IF, sigmoid function	Above 0.5m risk is 0.3 Below 0.1m risk is 0 Between is S-curve centred on 0.25m depth, with risk maximised at 0.3m

4.Residents	IF(x>0.09,1, 10x)	IF function, linear	Above 0.09m risk is 1 Below this is a linear increase with depth
4.Properties	IF(x>0.19,1, 5x)	IF function, linear	Above 0.19m risk is 1 Below this is a linear increase with depth
5.Property	IF(x<=0.2,0, 1.125x-0.225)	IF function, linear	Linear increase with depth above 0.2m
5.Residents	IF(x<=0.35,0, 0.7692x-0.2692)	IF function, linear	Below 0.35m risk is 0. Linear increase above.
5.Gardens	IF(x<=0.4,0.75x, 0.1667x+0.2333)	IF function, linear	Linear increase with depth, rate slowing above 0.4m
6.Property	x^2	Exponential increase	Risk increases slowly at first then at an exponential rate
6.Residents	$\frac{0.8}{1+exp^{-6(x-0.67)}}$	Sigmoid function	S-curve centred on 0.67m depth, with risk maximised at 0.8m
7.Residents	IF(x>0.09,1, 10x)	IF function, linear	Above 0.09m risk is 1 Below this is a linear increase with depth
7.Property	IF(x>0.25,1, 4x)	IF function, linear	Above 0.25m risk is 1 Below this is a linear increase with depth
8.Residents	$\frac{0.4}{1+exp^{-8(x-0.45)}}$	Sigmoid function	S-curve centred on 0.45m depth, with risk maximised at 0.4m
8.Property	$\frac{0.8}{1+exp^{-25(x-0.3)}}$	Sigmoid function	S-curve centred on 0.3m depth, with risk maximised at 0.8m

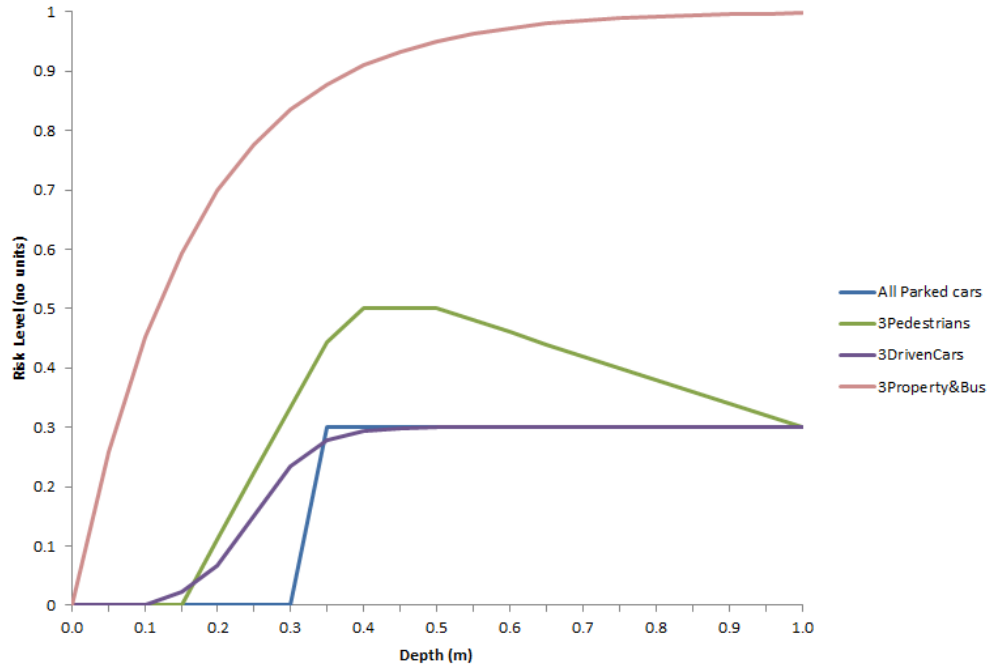
Location 1: Halloughton Road


Risk Level (no units)
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
All Parked cars
1Property
1Residents

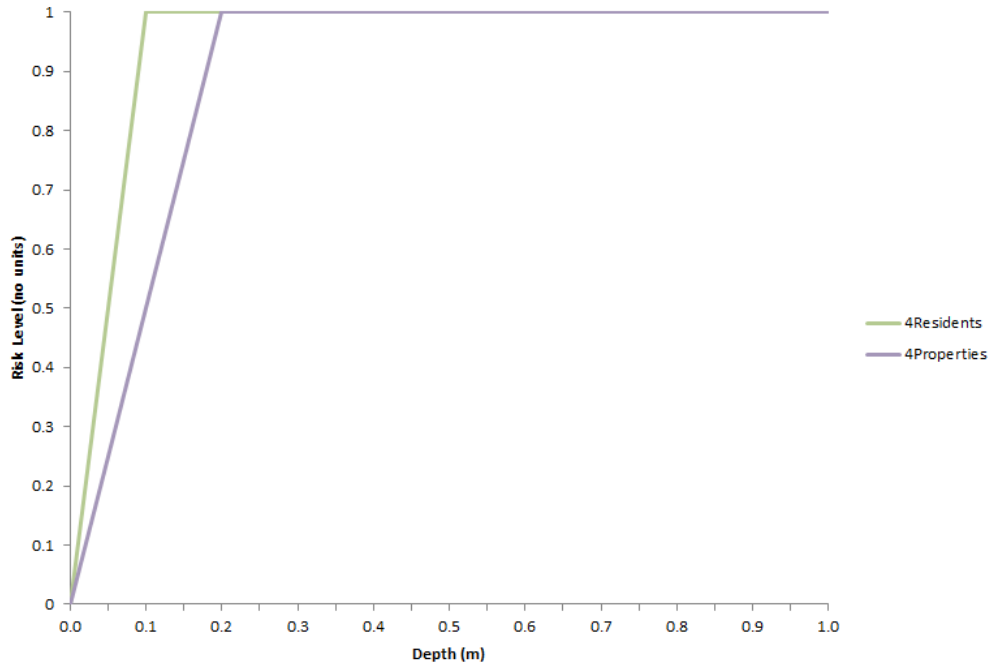
Location 2: Nottingham Road



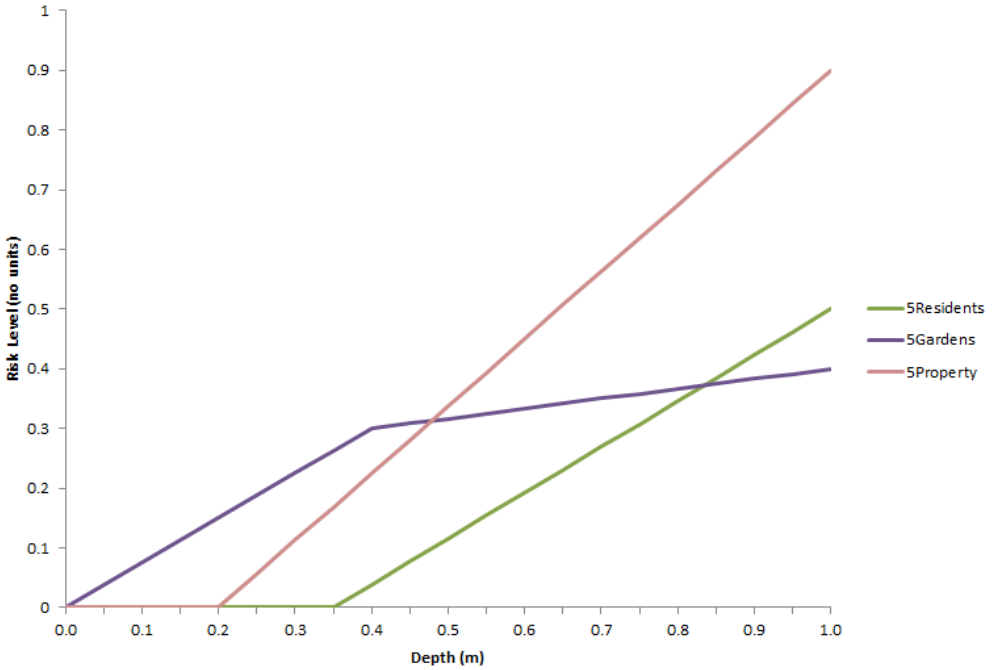
Location 3: Church Street



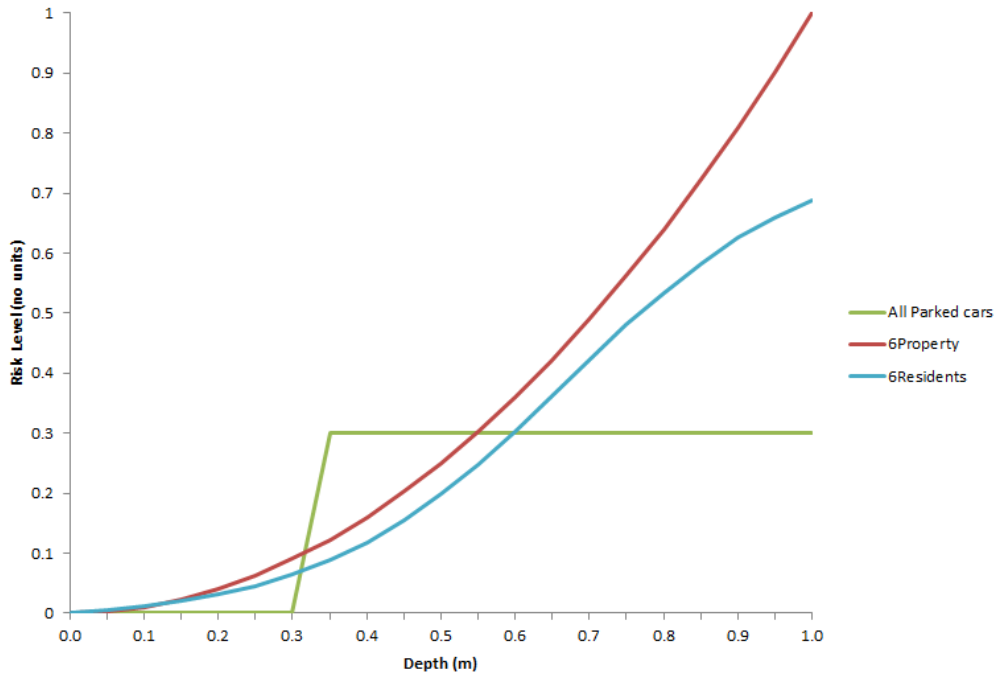
Location 4: Potwell Close



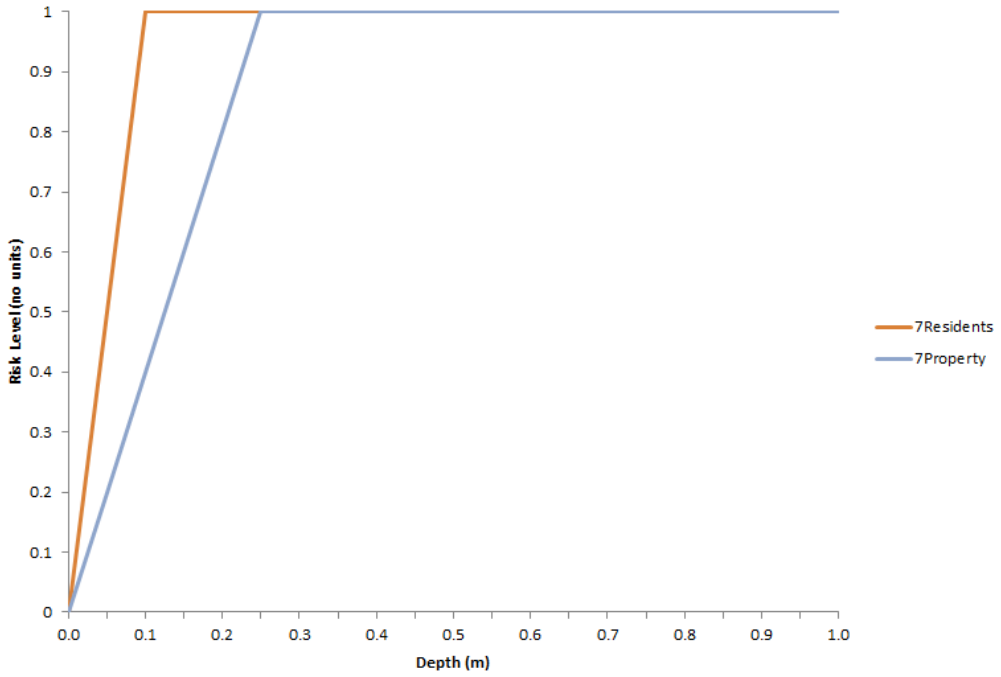
Location 5: Ropewalk



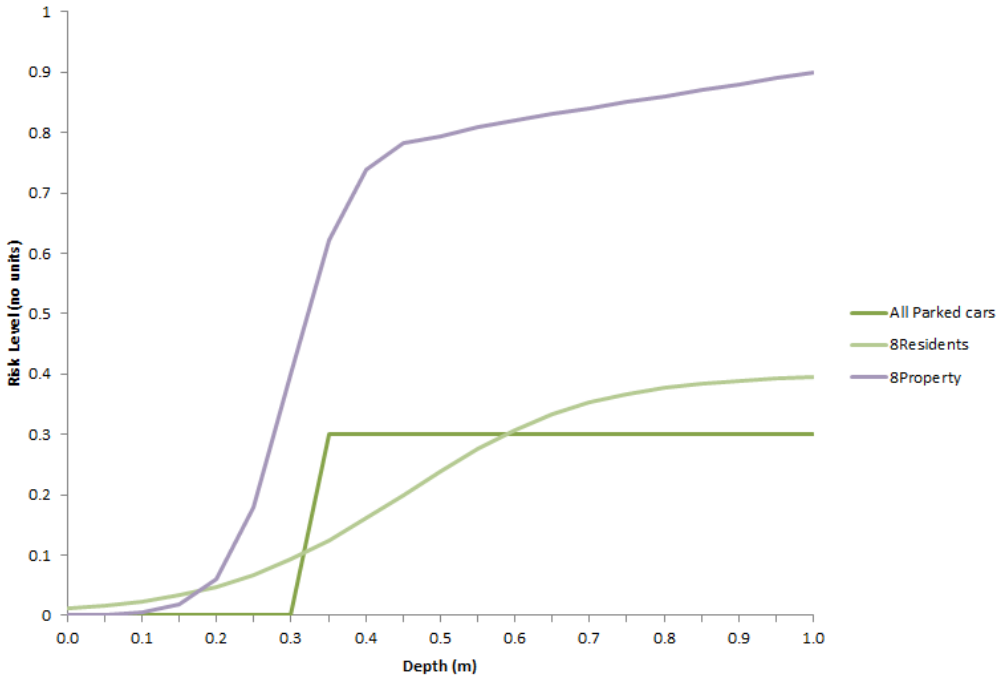
Location 6: Archers Field



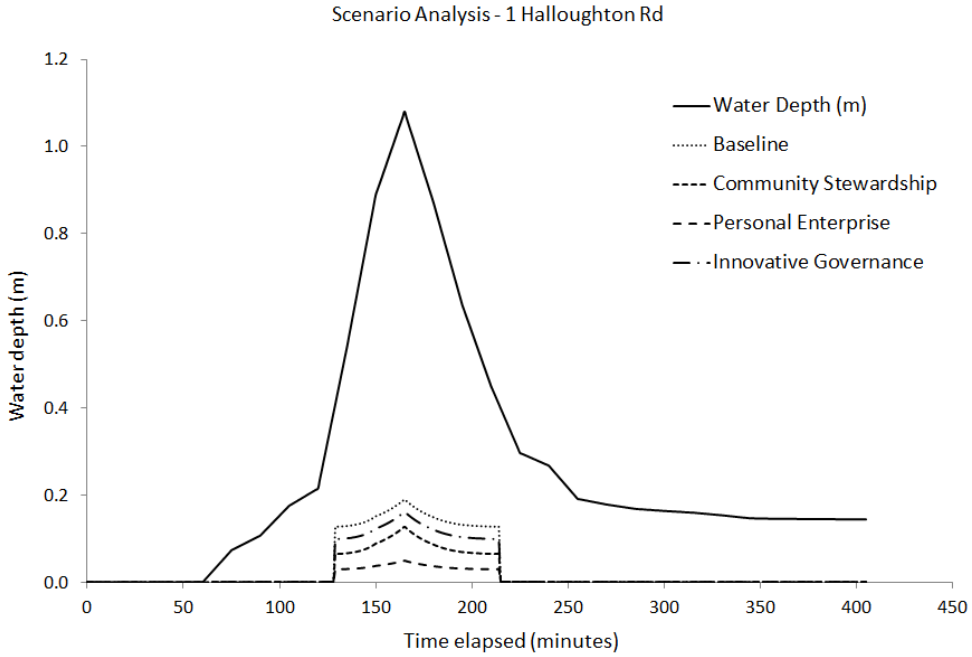
Location 7: Merryweather Estate

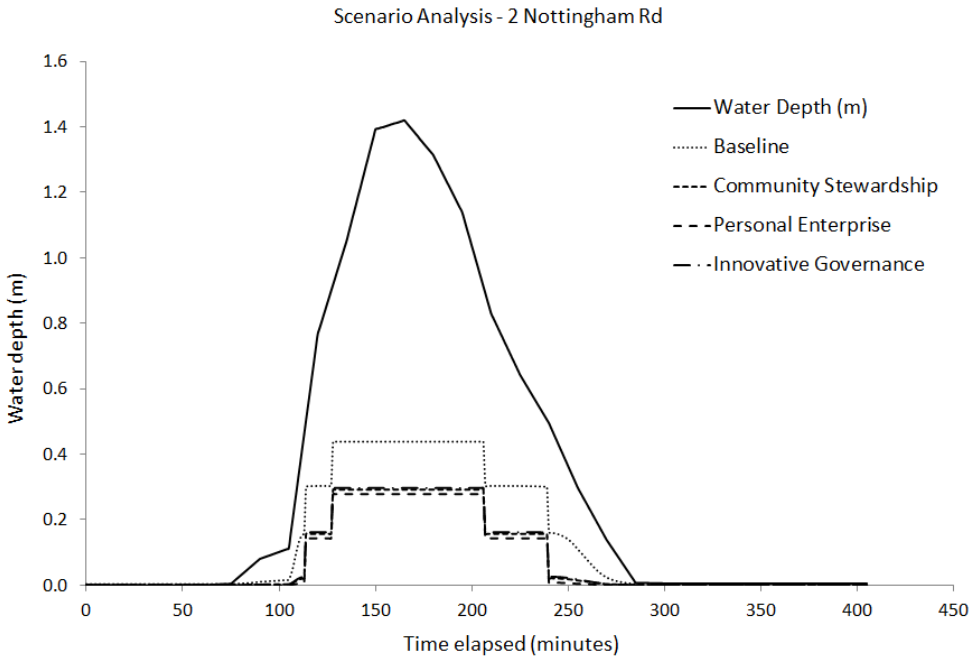


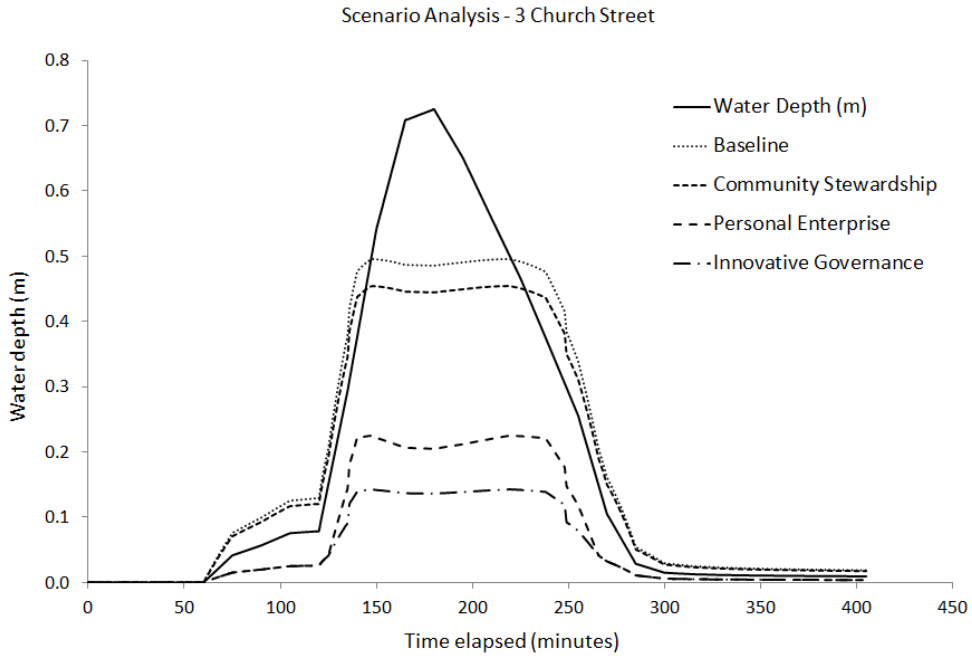
Location 8: Crafts Way

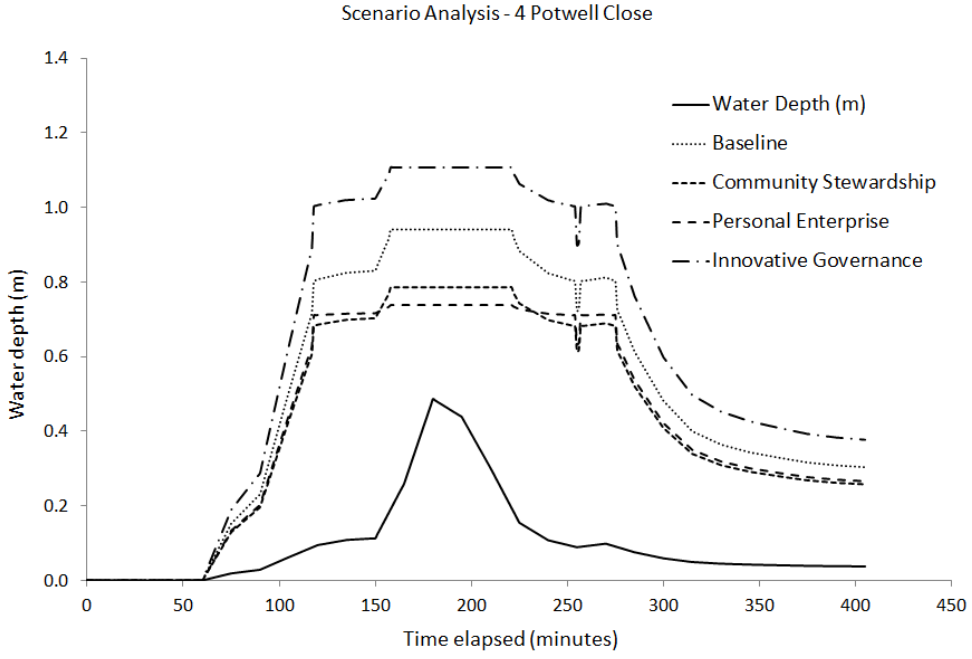


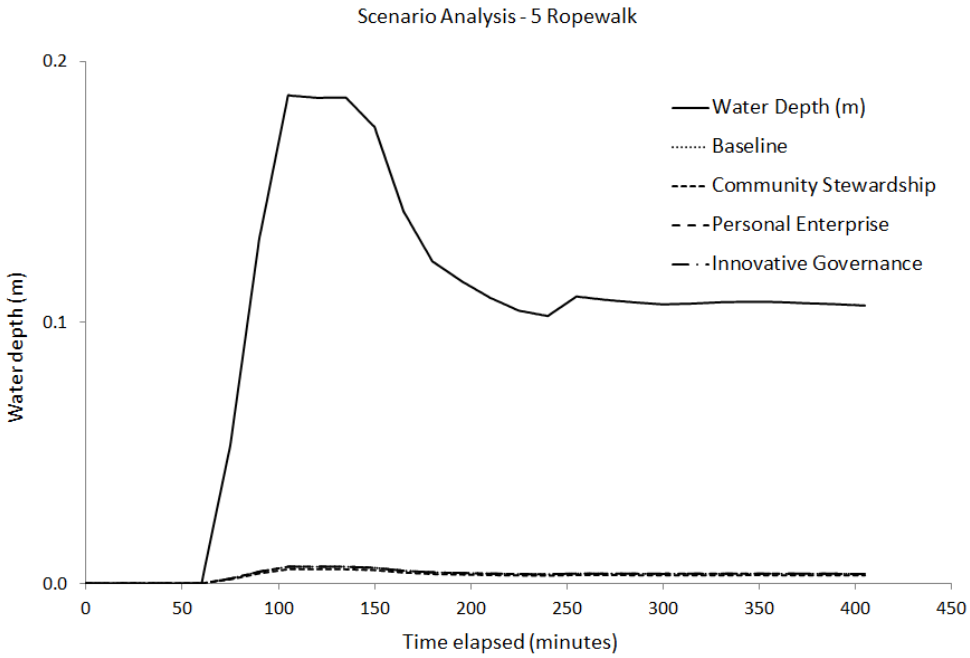
Appendix 8: Model outputs

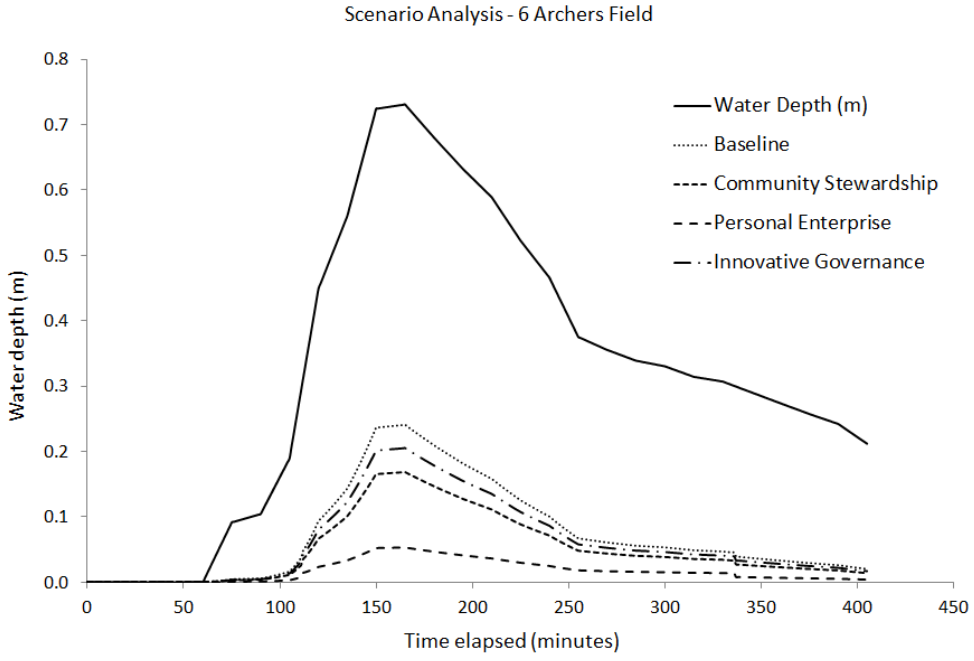


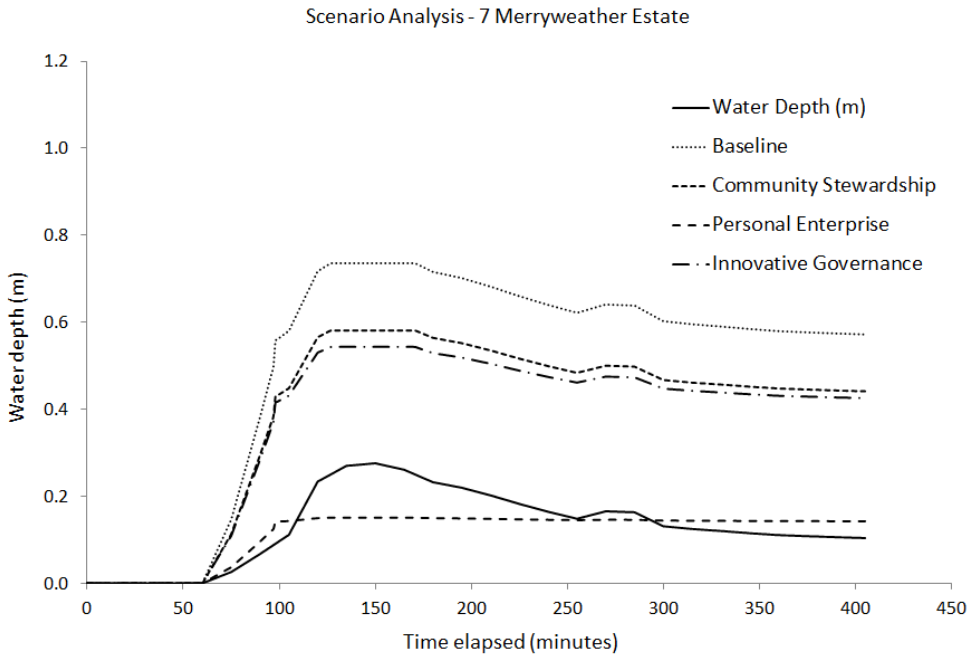


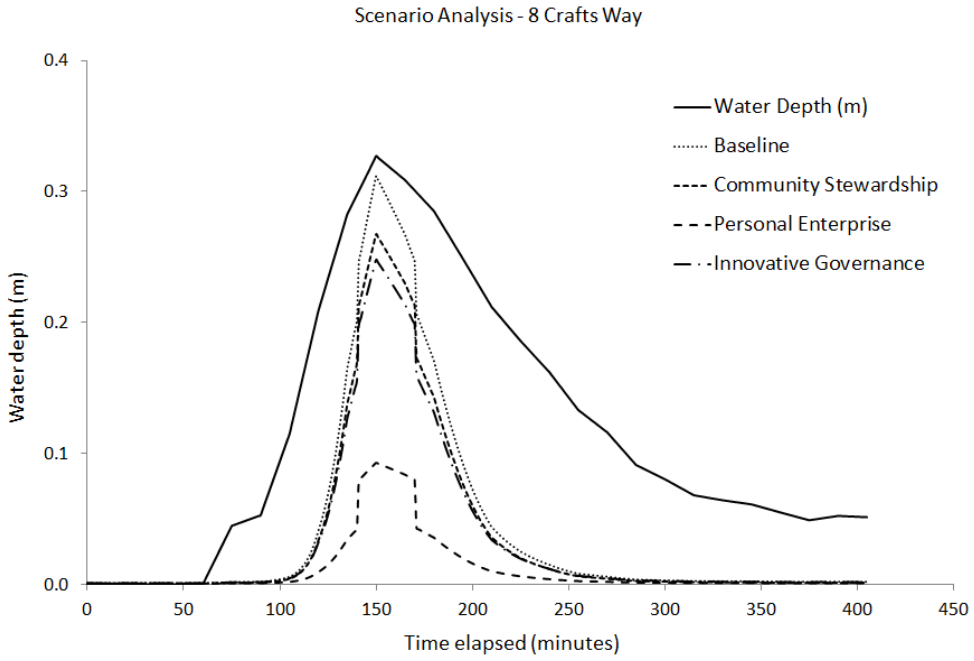

Scenario Analysis - 3 Church Street
Water depth (m)
Time elapsed (minutes)
Water Depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
50
100
150
200
250
300
350
400
450


Scenario Analysis - 4 Potwell Close
Water depth (m)
Time elapsed (minutes)
Water Depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
50
100
150
200
250
300
350
400
450


Scenario Analysis - 5 Ropewalk
Water depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
Water depth (m)
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
450
Time elapsed (minutes)


Scenario Analysis - 6 Archers Field
Water Depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
Water depth (m)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
450
Time elapsed (minutes)


Scenario Analysis - 7 Merryweather Estate
Water depth (m)
Time elapsed (minutes)
Water Depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200
250
300
350
400
450


Scenario Analysis - 8 Crafts Way
Water depth (m)
Time elapsed (minutes)
Water Depth (m)
Baseline
Community Stewardship
Personal Enterprise
Innovative Governance
0.0
0.1
0.2
0.3
0.4
0
50
100
150
200
250
300
350
400
450

Appendix 9: Post-project interview codebook for Southwell

In vivo codes from the post-project interview transcripts are collated and organised according to the evaluation criteria outlined in Paper III, Section 7.

Process Evaluation

(P1/2) - Accessibility

In vivo code	Analytic code
Some jargon used which some people don't understand	Use of language
Language sometimes a bit ambiguous	
The technical aspects and language were complicated to start with	
Some of the language used was hard to take in	
When new language was introduced it was not always clear	
There is probably more I could have gotten out of it if I had understood a bit more	
Difficult to say whether the process would have suited less educated people	
Very important to go back to basics	
You realise you need another hour [lots of time]	Time commitment
Missing workshops did not cause a problem	
Going to several workshops built up a picture of what was going on	
Process required a time commitment	
It was very easy to get involved as much or as little as you wanted	
Difficult for people to commit to attending the workshops	
Newsletter kept in touch, especially with things people had missed	Communications
Communication was done really well	
The weekly newsletters were really useful	
Communications summarised the workshops well	
Between-workshops communications were very good	
Between-workshops communications kept interests up	
Communication helped when workshops were missed	
Objectives key to everything	General accessibility
As process went on, could see why we were doing things	
Takes some getting used to	
Accessibility was as good as could be expected.	
Easier to understand when help from a facilitator is available	Facilitation
Took a bit of brain power to get my head around	
Well explained	
Required good facilitation there to keep on track	
It was explained well	
Particularly enjoyed the hands on working in the first workshop	

(P3) - Deliberation

In vivo code	Analytic code
Good to work with different people in small groups	Group working
Small groups meant that participants were not involved in all aspects (x2)	
The knowledge transfer was good because the group were quite diverse	
A lot of it was quite subjective, and it depended on who you had got there	
Made us think about the wider [picture], and what we were going to do	Praise
People felt comfortable bouncing ideas off one another	
Met new people	
It did increase our knowledge	
More deliberation in workshops than between them	Criticisms
Not sure if consensus/agreement carried forwards from workshop to workshop	
Not sure whether the costs of having people together in this way outweighed the benefits	

(P4/5) - Representation

In vivo code	Analytic code
Those of us from different parts of the town would bring [different experiences] to the debate	Geographic/spatial diversity
A range of people attended	
Variety of different people	
The group makeup was appropriate to represent the community	
Not a problem that is was not representative of the town	
Some areas of the community were poorly represented	
Some areas of the town (Halam Hill) could have been better represented on one occasion	
I think we had a reasonable cross-section of flooded and not flooded	Affected vs. unaffected
Representative of motivated people	
Because they were interested in flooding, and knew a bit about the flooded areas, they could make positive contributions	
Not all participants were affected by flooding	
Some of the more vulnerable groups were not well represented	
There were relatively small numbers of people who'd been actually flooded	
A few practitioners were present	Practitioner involvement
I would have liked to have seen more input from practitioners	
All of the people were from the Flood Forum	
Outside agencies could have been more involved, but they are busy	
Everybody had the opportunity to speak	Opportunity to contribute
It felt a safe place to make a contribution	
People felt able to contribute	

Felt free to make a contribution	
The process was strong at allowing everyone to make a contribution	
The fact that most participants were older did not make a lot of difference	General comments/criticisms
Group was missing those with stronger views	
A range present, but some missing	
Process would have benefitted from more participants	
Such a small group cannot represent the full range of views	

(P6/7) - Responsiveness

In vivo code	Analytic code
You had to make some alterations or modifications to what you were going to do	Flexibility in approach
Flexible across process but not in individual workshops	
Process adapted as needed	
Process was sufficiently flexible while being structured	
Focus on task in hand, didn't think about flexibility	
I think you did change course significantly mid-stream	
Agenda was already worked out	Flexibility within workshops
[linked to above] not a problem – you need an agenda	
Flexible across process but not in individual workshops	
Approach was fairly scientific	Methodology – general comments and praise
Method was explained clearly	
Method good for bringing breadth of knowledge together	
Method seemed fit for purpose	
Straightforward and easy to follow.	
Activities were adequately pitched for the age breakdown	
Some of the activities, particularly when used in a small group, were subjective (x2)	
Methodology was fit for purpose	
Methodology was adequate	
I didn't see any area where we found difficulty putting Southwell's experiences in the process. Either experiences, or figures, or rainfall or whatever, it was all fairly logical. [KEY QUOTE]	Methodology - context
I don't remember coming across any situations where I thought it didn't' fit what we were talking about, or it didn't fit Southwell.	
You overcame as best I think you could reasonably have done the problem of there being a general flood model going on at the same time	Methodology - criticisms
Not always easy to follow	
Project struggled to deliver 'evidence' in relation to the 2013 flood, as a result of the subjective nature of inputs	

(P8/9/10) - Satisfaction

In vivo code	Analytic code
Not sure everybody knew what to expect, or what was expected of them	Expectations
Expectations unclear at outset, but soon explained	
Expectations became clearer as time went on	
Expectations of participants clear	
Expectations of what participants could gain is unclear	
I wasn't sure what we were going to get out of it	
We didn't know initially what would be expected of us	
Became clear once it was all explained	
Expectations became clearer as the process went on	
We knew what we were trying to do	Understanding
Continually trying to get head around it	
Became clearer	
Support available in workshops	
Can see whether it is going	Vision/objectives
Objectives and direction clear	
Understanding of goals improved over time	
Became clearer over time	
More needed to be said at first workshop about direction, objectives, etc…	
Purpose was clear	
Needs and goals were set from the start, but were fairly well-aligned	
Very professional	Facilitation
Impressed with the way it was presented	
Facilitation was very professional	
Not sure what happens now	Outcomes
Unclear what the tangible outcomes will be	
Process is ongoing	
Process could never have delivered on certain needs (i.e. solutions)	
Disappointed by the drop-out rate	General comments
Process was overshadowed by other developments elsewhere (release of flood model)	
Pre-communications were good	

Social Outcome Evaluation

(O1/2/3) - Knowledge

In vivo code	Analytic code
We are better equipped and more knowledgeable than we were	Generating new knowledge
Discussion explored risk and broadened out	
By joining in the process people learnt more about where they would go and what they would do	
Process attempted to explore different mitigation strategies	
Didn't see many new interventions identified (x2)	
Nobody was short in coming forward with opinions	Sharing knowledge
People were able to give their actual experiences	
Increased discussion about risk within the Flood Forum	
Interesting to hear about others' perceptions of risk	
Sharing knowledge about risk was a fairly strong area	
I can't think of any situation where we weren't encouraged to come up with ideas, responses and so on [KEY QUOTE]	
Was able to provide advice and knowledge from own experience	
The participants were able to share knowledge, but it would have been better to have a larger group	
Participants generally already knew who to go to for support	Support
Already knew who to go to for support	
Other activities outside the process were more important in providing support for residents (x2)	
This objective was supported by activities outside of the process	
I think we've stripped back, as the flood recedes [KEY QUOTE]	Benefits/praise
Tool helps to keep flood risk in people's minds	
It gave us a greater understanding of what was going on, and where the problems lay	
I think probably what it did was focus our attention in the right places [KEY QUOTE]	
Helpful to meet other affected residents	

(O4/5) - Motivation

In vivo code	Analytic code
[Lists some interventions]	Identifying interventions
Process could have been stronger at identifying interventions	
I don't think we identified those measures through your study	
I thought they were taking ownership of it as 'our problem'	
The fact that they came along meant they were already willing to be a bit more proactive	

Attending certainly wouldn't have done them any harm	Ownership and responsibility
Process helped support motivation levels that were already high	
Process encouraged participant to become a flood warden	
Process got new people engaged with flood risk issues	
Process helped motivate people to take action	
Levels of motivation were already high	

(O6/7) - Networking

In vivo code	Analytic code
Trust improved within the group	Trust
Developed trust within the community but not particularly outside	
Trust improved within the group, but not particularly with outside agencies	
Little involvement from outside agencies meant trust could not improve	
With regards the building of trust, other concurrent influences outside of the workshops had a greater impact	
There were many people I didn't know.	Resident – resident links
Certainly people met people they didn't know	
Relationships were already there	
Process would create networks in a community where they didn't already exist	
Southwell is already highly engaged with the flooding process	
Relationships within the community rather than with organisations	
Getting to know those involved in local FRM (i.e. from the Flood Forum)	
Useful to talk to other affected residents	
It was the first time that I had spoken to Sue Jaques properly, outside of the meetings	Resident – agency links
Links developed between organisations (NTU) and local community	
Formed new relationships	
Disappointed that the EA and LLFA had little involvement	
Little involvement from outside agencies meant trust could not improve	
It would have been a lot better if people from different agencies had attended workshops	
Attendance from agencies would have helped people understand what they do (x2)	
Would have been nice to meet people from the agencies	
Process driven by a small cluster of people, a 'key group'	Group dynamics/benefits
Found working with new people useful	
Useful to talk to others that has been through a similar experience	
More participants were needed for effective networking	
It did bring people together to put forwards ideas and thoughts	

Substantive Outcome Evaluation

In vivo code	Analytic code
Interesting to hear about others' perceptions of risk	Improved understanding of the public perception of risk
Increased discussion about risk within the Flood Forum	
The weekly newsletters were really useful	Exchanging knowledge
The knowledge transfer was good because the group were quite diverse	
Important to get the full range of ideas and views from the community	
I would have liked to have seen more input from practitioners	
Disappointed that the EA and LLFA had little involvement	Improving understanding of the role of different agencies
Developed trust within the community but not particularly outside	
Empowered the community to take responsibility	
Strengthening the messages of the forum	Strengthening key messages
Process was highly organised, and prevented the group from entering prolonged discussion without focus	
Participation fosters the taking of responsibility	
Value of the model as the product of a thoughtful deliberative process	
Thinking about risk holistically and in a structural way.	Using the process to identify all possible intervention options
Highlighted all possible options, noting was overlooked	
Focussed thinking on key interventions that have the greatest impact	
Relationships were already there	
Approach was flexible and suited different participants	Bringing people together and increasing public involvement
Opportunity for those less articulate or less confident to participate	
Intensity of programme may have put some participants off	
Importance of involving people outside of the 'core group' of usual volunteers	
A forum for getting views and ideas from people outside of the 'core group'	
Still some people are hard to reach	
Some people would have been put off by the process	
You don't want to predict at the beginning what the outcomes will be	
Difficult when you do not know where the project is going	Emerging challenges
Getting news/outcomes from the project to a wider audience	
Hard to sell a process as offering 'something for everyone'	
People don't realise that local information is valuable	