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Public participation in river research
and management: scale, levels of
participation and the contexts of
knowledge co-production

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Thesis submitted for the degree of
Doctor of Philosophy

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2013

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Public participation in river research and management: scale, levels of participation and the contexts of knowledge co-production

The call to utilise participation in river research and management has grown steadily over the last few decades and features in many policy guidelines (most notably the Water Framework Directive). However, with little detailed guidance on the appropriate levels of participation, and on the appropriate participants, river management organisations are left to determine these for themselves, within given temporal and financial restrictions. Consequently, participation often comes second to meeting the environmental goals of the organisation. It is argued here that participation need not necessarily be viewed as an ‘add-on’, but that when used effectively, it can be beneficial both to the environment and the communities involved. Furthermore, within any aspect of river research (academic or managerial), participation of those who live daily with the river can enhance process understandings and lead to context specific research. This study, therefore, aimed to identify and evaluate innovative approaches to river research and management which place a focus on the integration of a diverse range of knowledges, in an effort to move beyond the traditional scientific approaches, focusing on the acclaimed benefits of high-level participation and knowledge co-production, in a range of situations.

The two-step approach, involving a review of organisational practice and a local case study, was both interdisciplinary and participatory. The methodological approach allowed the Organisational Review step to provide context for the wider project, while the case study focused on the development of research objectives *with* the community who would be affected by their outcomes. The integration and deliberation of both scientific and experiential knowledge led to a process of knowledge co-production among the participants.

The results of the participatory investigation into the impacts of weir restoration (on the River Derwent in County Durham/Northumberland) suggested that changing the profile of the weir would cause some localised, small scale changes to hydraulic aspects such as flow level upstream of the weir, but that flow rate and sediment transport would be relatively unaffected. The Organisational Review concluded that factors such as scale, resources, motivations and attitudes strongly influenced the uptake and success of participatory processes.

Analysis of the participatory approach led to the conclusion that selection of a single participatory approach may be unsuitable in practical situations due to the changing nature of projects, and that a reflexive approach is likely to increase the success of participation. Universal application of high-level participation is recommended only with caution and the context of each individual project should be carefully considered before opting for the approach. Existing environmental controversies can be utilised to facilitate co-production of knowledge through a high-level participatory approach. While caution and contextual consideration are advised, high-level participation can offer a number of benefits, including the co-production of a context-specific knowledge, relevant research questions, and social learning for all involved. The results showed that experiential knowledge can be highly valuable in researching and managing rivers at a range of scales.

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Terminology

Much of the terminology associated with participation is used widely and often in varying contexts. Therefore, the appropriate definition of some terms has become ambiguous, and sometimes applied inappropriately, or even used to mask the nature of a certain process or approach. For this reason, terminology specific to use within this thesis is included at this stage, to provide clarity and avoid the mis-use or mis-interpretation of terms.

Term	Description
<i>Processes</i>	
Participation	In this context, 'participation' is used to define any process through which 'external' parties are involved in any aspect of decision-making or knowledge creation (e.g. river management or research)
Organisational Review	Interview process conducted with a number of river management organisations in the UK and Europe to determine approaches to participation
Ebchester Study	Reach-scale, participatory, interdisciplinary study which was used to examine the role of a competence group in the creation of knowledge about a river
<i>Actors</i>	
Interviewee	Refers specifically to those involved in the Organisational Review. Denotes the individual with whom the data collection interview took place, speaking on behalf of their organisation
ORO ('Organisational Review' Organisation)	The river management organisations specifically investigated in this project. ORO is used to provide a distinction between those investigated in the study, and organisations when discussed more generally
River Managers/ Organisations	Management organisations in general – referring to all those charged with river management, not solely those taking part in this study
Scientist	Individual, usually in a research position, who investigates and advises on physical or scientific processes and questions (e.g. river management projects)
Local expert	Usually individuals, or members of self-assembled action groups with local/personal knowledge/experience in the project. Often personally affected by management measures
Stakeholder	Participants with a professional/semi-professional background who may advise on or steer decisions, but have less control than managers or scientists. Often represent wider interest groups. May include professionals in a related discipline, or charities. When referring to the term as used by another author the meaning may differ and this is noted within the text
Intermediary	Organisations or individuals who are intended to communicate between and facilitate interaction between 'scientists' and 'local experts'. Also often charged with the task of implementing measures once they have been decided
Public	Any individual or wider group who has an interest in, or who may be affected by, a project
Participant	Any individual taking part in a participatory approach (see above for participation)

'Certified expert'	Also termed 'traditional' expert, a person or group who are 'traditionally' qualified (e.g. through academic or professional status) to research a specific topic
'Non-certified expert'	An individual who is not traditionally qualified (see above) to research a topic, but who possesses <i>experiential knowledge</i> gained through personal interaction with a process or issue. This experiential knowledge qualifies the individual to comment on the process or issue (certified and non-certified experts defined according to Lane <i>et al.</i> , 2011)
Practitioners	In this case, individuals or groups who are responsible for implementing change and who instigate a participatory process to do this
Competence group	Group of individuals with a shared concern or goal, and appropriate knowledge, which is assembled to research and address an issue
Concerned Group	A term used by Callon (1999) to describe a group with a 'specific shared identity' – in this case a concern and knowledge about the physical processes of the local area. <i>Used in discussion of Callon's models.</i>

Chapter One

Introduction

1.1 Research problem and approach

For many decades, river management has been dominated by hard engineering approaches (Sear *et al.*, 1995), which traditionally were based on knowledge and data provided by certified experts. Within river research (and broader scientific research), knowledge that was produced was done so in response to personal interest, without application to a specific context, and was exclusively for the ‘scientists’, with members of the public hoping to be, at best, *informed* (Gibbons *et al.*, 1994; Callon, 1999) of research findings or management activities. More recently, there has been a shift in management approach, in which softer engineering approaches (Adams *et al.*, 2004), have been adopted which aim to work with the river and the riparian environment, rather than to control it. This change has occurred in response to new attitudes towards research and management, which suggest that research should be application specific, answerable to those whom it affects and inclusive of those who possess information which is not traditionally scientific (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001). Additionally, the emergence of the argument that the public have a democratic right (e.g. Jasanoff, 2004a; Reed, 2008) to be involved in management decisions which affect their homes, livelihoods and communities has been reflected in policy and planning guidelines (most notably for the UK and Europe, in the Water Framework Directive: WFD) and the value of ‘public knowledge’ has been proposed.

Subsequently, a wealth of literature has promoted (and to some degree demonstrated) the benefits of public involvement in river management and research, although uptake of public participation at the prescribed higher levels (in which some members of the public are given a certain level of influence or control over knowledge production and decision-making processes) remains rare in practice. The aim of this study, therefore, was to examine the disconnect between academic/policy recommendations, and practical implementation of an approach which is

claimed to be both beneficial and deserved. The value of higher-level public participation for co-production of knowledge is assessed at several scales and the practicality of the approach is considered for a range of river research and management organisations.

Motivated by the above issues, and following reflection on a number of fields of literature, this thesis aims to identify and assess the context and use of innovative research approaches which focus on the incorporation of environmental knowledge in all its formats. This implies moving beyond the traditional 'scientific' approach currently institutionalised in research and management and examining the ways in which participation, knowledge sharing and knowledge co-production work in practice. The primary research questions for the study, which have been developed based on the current position of river management and knowledge production theory within the literature (see Chapter Two, and Section 2.6 specifically, for research questions), address a number of themes, including:

1. The range of current approaches to public participation in river management and how any chosen participatory approach is affected by the project and the context.
2. The assessment of more innovative approaches to river research and management, which utilise participation and focus on societal outcomes as well as environmental ones, and aim to help *all* participants learn through the process, and achieve outcomes. Associated with this, is the examination of appropriate tools in achieving these outcomes, and the identification of relevant participants, the evaluation of 'levels' of participation, and the major barriers which may prevent (or have prevented) the uptake of higher-level participation.
3. Specific attention is paid to the value of experiential knowledge in such research and management approaches. Much attention is given within Science and Technology Studies (STS) literature to modes of knowledge production. This thesis examines the extent to which these theories are applicable in practical research and management situations, and whether the acclaimed 'controversy' (see Section 2.3.7) is the only situation in which true knowledge co-production can be achieved.
4. The importance of scale in how far people and organisations are able and willing to co-produce knowledge, select participatory approaches and utilise experiential knowledge is considered, leading to the broader question of whether co-production can be achieved for large scale projects (and therefore in many river management situations).

In order to address the above themes and the research questions, a two-tiered approach was adopted for the study. This consisted of i) a review of participatory approaches adopted by river management organisations (the 'Organisational Review'); and ii) an interdisciplinary, participatory study, which was nested within the bigger project and which produced its own research questions and findings (the 'Ebchester Study', named from the location of the study). The Organisational Review was designed to produce independent results to address the question of how participation is currently viewed and conducted in river management organisations across a number of scales. However, it was also designed to establish the context for the positioning of the experimental aspect of the project (the Ebchester Study). Some of the findings from the Organisational Review were used to determine the aspects of participation which presented real difficulty to organisations, or which were absent from their practice. The *in-depth* involvement of the public was the main aspect which appeared to be lacking in many of the organisational projects investigated. Therefore, a study of the benefits and difficulties of a high-level participatory process and knowledge co-production (supported by the relative rarity of empirical examples within the literature) became the focus of the Ebchester Study.

The Ebchester Study aimed to assess the value of a high-level participatory research approach to addressing a problem that was significant enough to a group of citizens to have brought them together in action (the issue of weir restoration on a river). A high-level participatory approach was adopted (Participatory Action Research, PAR) in order to allow a group of interested individuals to bring together their own experiences and understanding of a river reach, and create a new knowledge, based on the processing and re-processing of the various knowledge formats. The project was also an interdisciplinary one, addressing both environmental and social needs, utilising research methods grounded in the disciplines of physical and of human geography, as well as considering other aspects of river management, such as ecology and engineering. This holistic approach is considered vital for a thorough understanding of a river system, as one aspect cannot exist independently of the others (discussed by Harrison *et al.*, 2004). The study catchment of the Derwent, which lies on the border of County Durham and Northumberland (see Figure 5.3), was selected because of my own research familiarity with it (which included knowledge of some of the catchment's primary issues), and because of the currently available physical data (e.g. flow data). The specific site for investigation (Ebchester) was selected as part of the participatory process and a detailed description of the study site can be found in Chapter Five. The case study (chosen for a number of reasons, as discussed in Section 3.4.2) was based around a degraded weir and a group was formed to investigate the potential impacts of weir restoration. The participatory approach was used to identify specific and appropriate questions,

around which the research was based (focusing on the potential impacts of weir restoration). These questions, independent of the wider thesis research questions, have been termed 'EWRG objectives' (EWRG is the Ebchester Weir Research Group). The objectives address a number of questions:

1. How will a changing weir profile affect water level, and the use of the pool upstream of the weir?
2. How will a changing weir profile affect sediment dynamics both upstream and downstream of the weir?
3. Can voluntary labour be used to remove vegetation from the mid-channel bar, and what impact will this have on flow rates, flood risk, etc.?

After their formulation, the EWRG objectives were addressed through both qualitative and quantitative means. Qualitative approaches were used to collate experiential knowledge and scrutinise traditional scientific data. The quantitative approach involved data collection and processing for use in a hydraulic model of the river. This model was used to predict the response of various riverine characteristics such as flow rate, velocity, sediment dynamics, etc. to a change in the profile of the river, brought about by a changing weir structure. The participatory approach allowed the assessment of the model both in environmental and societal terms (and therefore a combined approach, rather than individual qualitative and quantitative components), and assisted in further model development. The implications and effectiveness of the approach for the group involved, and for the environmental findings, form the basis of the discussion for the thesis and are combined with the findings from the Organisational Review, to address the wider questions about participation in river research and management.

This chapter first introduces approaches to river management in recent years and describes how the change in river management approach has led to higher levels of participation being called for (Section 1.2). The wider topic of participation is then discussed and reasons for using participation are presented (with examples drawn from river management literature) in Section 1.3. Some of the dangers of participation are also discussed here and the different levels of participation available to river managers are outlined. Following this, the legislative requirements for increased participation in river management are presented (Section 1.4), for both the EU and specifically for the UK. In Section 1.5, the discussion switches from a general review of river management and participation, to the study approach for this thesis. PAR has been selected as the participatory approach for this study, and the reasons for this are described in this section,

followed by a discussion of the importance and the challenges of interdisciplinary research, with specific reference to this study. Finally, (Section 1.6), the thesis structure and presentation are outlined and illustrated with chapter summaries.

Following this chapter, the thesis is presented according to four parts, which include the theoretical frameworks on which the study is based (Chapters Two and Three), the Organisational Review (Chapter Four), the participatory, interdisciplinary Ebchester Study (Chapters Five, Six, Seven and Eight) and the synthesis of all findings and their implications for river research and management (Chapters Nine and Ten).

1.2 Current approaches to river management

It has been suggested that by 1996, up to 96% of the UK's river systems had been modified (Brookes and Long, 1990; Brookes and Shields, 1996). Modification of a river channel may occur for a number of reasons, including flood management, water diversion, land reclamation, commerce and development (Wissmar and Beschta, 1998; Boon *et al.*, 2000, 493). Wissmar and Beschta (1998) note that such adaptations cause changes to the river, floodplain and ecosystems, including fragmentation of riparian corridors (Hanson *et al.*, 1990; Dynysius and Nilsson, 1994) and lead to losses in complexity and connectivity between the riparian, channel and floodplain habitats to which aquatic communities are adapted (Gore and Shields, 1995; Ward and Stanford, 1995). In the past, rivers have been altered in an effort to maintain stability. However, rivers and the ecosystems are not stable: they are dynamic (Hobbs and Harris, 2001; Eden and Tunstall, 2006). It is believed by a number of authors (e.g. Connell, 1978; Huston, 1994; Gore and Shields, 1995; Ward and Stanford, 1995) that diversity of species is maintained by disturbance events and that human modifications reduce the occurrence of such events, causing changes in levels of diversity (Wissmar and Beschta, 1998). Therefore, restoration and management goals cannot be based on static attributes (Hobbs and Harris, 2001). The range of impacts that anthropogenic intervention can have on a river system is described by Wissmar and Beschta (1998) and illustrated in Figure 1.1. This figure demonstrates that many of the processes are interlinked and one alteration in the system can have complex implications. In order to address river restoration and management effectively, a number of disciplines must be considered, with emphasis on reflexivity, contextuality, substance and engagement (Lane *et al.*, 2006).

Until the 1990s, the dominant approach to river management was of hard engineering (e.g. Sear *et al.*, 1995), which focused on flood prevention. More recently, there has been a change in focus

so that restoration, rehabilitation and soft engineering solutions are now a priority, due to the dual aim of utilising *and* preserving nature through *sustainable* means (e.g. Adams *et al.*, 2004). In addition, it has been widely acknowledged that some form of public engagement is necessary as part of the river restoration and management process (e.g. Boon *et al.*, 2000, 91; Hobbs and Harris, 2001; Clark, 2002; Tippett, *et al.*, 2005; Wheaton *et al.*, 2006; Junker *et al.*, 2007; Petts, 2007). It has been noted that the complexity of river systems, the range of modifications that have taken place, and the widespread enthusiasm for river restoration measures in the developed world, have resulted in a lack of 'generic practices' and standard methodologies which can be referred to by river managers as forms of good practice (Wheaton *et al.*, 2006). Therefore, despite the call for a heightened level of public involvement, there is limited uptake from river researchers and managers. As noted by Boon *et al.* (2000, 503), one of the main questions that remain in river restoration is 'what do people want?'. Answering this question is imperative if managers and researchers are to achieve the prescribed democratic approach to knowledge development (e.g. Jasanoff, 2004a; Pahl-Wostl *et al.*, 2007), and involve those who are affected. Perhaps more importantly, those who are close to or with a situation or process have valuable knowledge and understanding which can result in a more effective management approach which considers the needs of *all* actors. Public engagement is the only way to address such a question and achieve these outcomes.

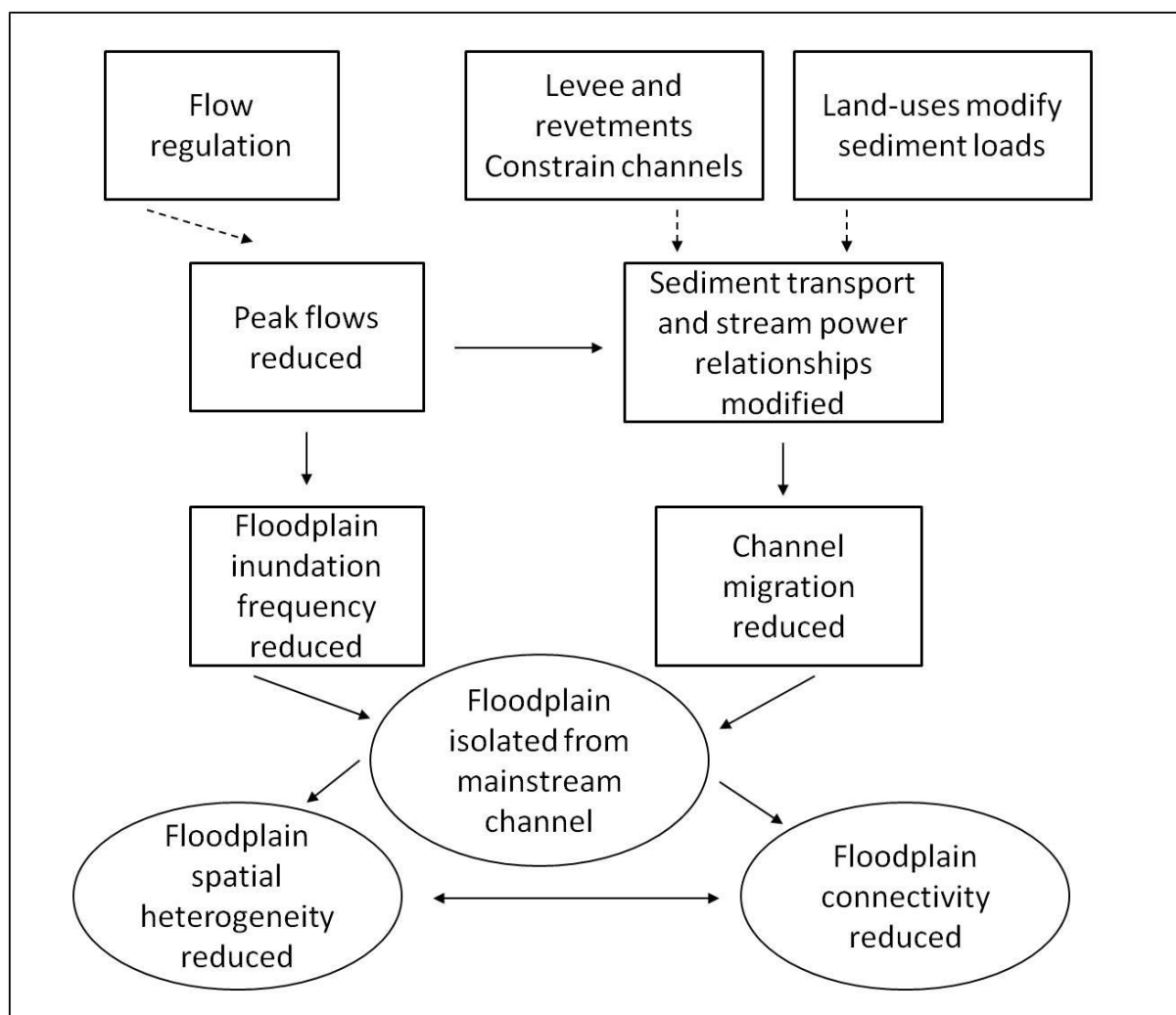


Figure 1.1 Potential influences of human activities on riverine attributes and processes, demonstrating the impact of a change to one feature/aspect on the rest of the fluvial system (After Wissmar and Beschta, 1998)

1.3 Public engagement and participation in river management

Participation can occur in many forms and is a process by which stakeholders or members of the public become involved in decision-making and research processes which may traditionally have been exclusive to certified experts. Broadly, the experience and knowledge possessed by participants is incorporated (to varying degrees) with the knowledge of traditional experts in order to address a question or problem. There are many reasons for participation (see below) and many approaches. Participation can vary greatly in terms of degree of involvement for participants and the varying levels of involvement have been the subject of numerous classification attempts, the most common of which is Arnstein's (1969) ladder of participation

(see Section 2.4.1). Lower levels of participation (e.g. consultation) are common in environmental management initiatives, but there is growing pressure for higher level involvement (e.g. delegated power or citizens control, see Table 2.3) to be more widely adopted. In higher level participatory processes, such as PAR, the process may be instigated by a group of non-certified experts which has been established to address a cause or issue of particular concern to that group and will ideally lead to the co-production of new knowledge about the issue. In such cases, traditional experts may still be involved, with varying levels of influence.

1.3.1 Reasons for participation

Recognition of participation as a tool for effective environmental management and, more specifically, catchment management has increased in the UK and Europe in recent years (Tippett *et al.*, 2005; Johnson, 2009). Participation in river management may be carried out for a number of reasons and these can be influenced by the individual or group that is carrying out the participatory process. For instance, policy makers and statutory bodies (e.g. the Environment Agency and DEFRA) are likely to focus on the environmental outcomes and how these may contribute to legislative requirements (e.g. Walker, 2004). Local activists, on the other hand may be purely concerned with a single or focused cause, such as the improvement of fish passage along a stretch of river. Other groups, such as charities (e.g. rivers trusts), may aim for a balance of both environmental and societal outcomes, and may see participation as a tool or valuable resource in this context (Maynard, 2013). Participation may also be used purely for research purposes, to develop and enhance knowledge and understanding of a certain fluvial aspect. The reasons for carrying out participation, informed by the remit of an individual or group, are likely to affect the way in which participation is approached and used. For example, those who use it as a tool to maximise group understanding of a system or process may wish to conduct high-level participation, in which the participants have a significant level of control over decisions. Those using the approach in order to meet legislative requirements, and who often have responsibility for managing large areas such as catchments, may limit participation to a process of structured consultation or 'placation' (Arnstein, 1969). If participation is used as part of an academic research study, it is likely that the researcher will have fewer practical constraints and therefore will be afforded greater flexibility in the nature and timescale of the participatory procedure.

The reasons for using participation in river research and management may also vary according to the nature of the work/study, but some key reasons are outlined here. First, it may be used to effect democratic decision-making in catchment policy development (Enserink and Monnikhof, 2003). This has been heralded as one of the major changes that need to be made to the way in which policy is developed (e.g. the principles underlining the Aarhus Convention and its rulings,

see Aarhus, 1998 and Section 1.4). Those who are affected by policies and by decision-making processes are entitled to have a say in the processes. Participation (of various forms) allows practitioners to involve those affected, consider their concerns (Eden *et al.*, 2000) and include their knowledge. It has been suggested that there are also environmental benefits to be gained as a result of improved quality and effectiveness of policy proposals (Enserink and Monnikhof, 2003). This may be due to individuals participating in such activities because of their own interests in the outcomes (Henriksen *et al.*, 2009). Therefore, their support for the outcomes is highly dependent on how they perceive quality in terms of their own preferences (Firth, 1998) and this impacts upon acceptance and affects ease of policy implementation.

Second, participation may be used to improve knowledge of a catchment, reach, or issue (Reed, 2008). Those who live with an issue, or have close/frequent experience with a river will possess a knowledge of that river which differs in nature to the general process knowledge 'of rivers' that is possessed by researchers. It may also be more specific, or long-term than data provided by any meaningful monitoring programme. Participation therefore allows different types of knowledge to be incorporated to improve the overall understanding of a place, system or problem, for all involved.

Third, participation can help to produce locally tailored schemes which are specific to a location or an issue and are therefore more focused, more relevant and potentially more acceptable to all involved (McDonald *et al.*, 2004). In addition to these benefits, the process of participation can also lead to the strengthening of communities and an increase in wellbeing, through a sense of belonging and worth of knowledge. Propagating from these benefits is the acceptance of a project and the potential sense of ownership and responsibility (House, 1999) which can be achieved by those involved, resulting from confidence they develop in their ability to provide knowledge and partake in decision-making (Petts, 2007).

Fourth, a participatory process can be used by organisations to capitalise on existing local skills and knowledge (Maynard, 2013), an important approach to using voluntary labour in a time of austerity. In using local knowledge in this way, participants feel their contribution is valued and necessary to the research process, and those aiming to achieve management goals can follow a process which is efficient and appropriately framed from the outset. It is imperative that participation carried out for this reason makes sufficient effort to consider the needs of the participants as well as the organisational goals, to manage expectations and to deliver what is promised at the outset. Shallow or misleading processes will result in poor (or no) community benefits and also a lack of support for that organisation which will be difficult to regain.

Fifth, trust in a project or decision can be gained if participants feel they have been given the opportunity to scrutinise, and contribute to, information (Yearley, 2005) that has been used in the decision-making or policy development process. In this way, lost trust in science (as documented by Beck, 1992) and management practice (Lane *et al.*, 2011), may also be re-built through transparent research processes and increased consideration of social as well as environmental factors (e.g. economic and political implications of research findings) (Henriksen *et al.*, 2009), in which participants have had a role. Conversely, the academic and managerial lack of trust in experiential knowledge must be addressed if participation is to be adopted effectively (e.g. Junker *et al.* 2007). The very process of participation may serve to highlight the value of experiential knowledge to sceptics, and encourage further integration, but practitioners must be reflexive and open-minded in their approach.

Finally, the democratisation of science (as recommended by Jasanoff, 2004a) can be achieved by allowing participants to contribute to the production of new knowledge, question the various aspects of the knowledge production process and have some control over final conclusions and decisions (the basis of knowledge production theories presented by e.g. Funtowicz and Ravetz, 1993; Gibbons *et al.*, 1994; Callon, 1999). This type of outcome requires higher-level participation and a great deal of commitment from all actors, and is discussed in Section 1.5.

Although there are many benefits to be gained from a participatory process, care must be taken to carry out the process fully and with just motives. Negative or nonchalant attitudes held by those introducing a participatory process can have detrimental results for both the environment and the communities involved. The danger associated with many of the above points is that organisations may use participants as they require their input, but neglect to afford them any real power or respect. In this case, they risk disenchanting the participants and losing support and vital knowledge contributions (Reed, 2008). Furthermore, participation is, in theory, used for the benefit of the participants as much as it is for the benefit of the environment (if not more so). However, it is easy for practitioners to focus upon their measurable outputs (such as improvement in water quality or reduced flood risk), and ignore societal benefits such as building community resilience or empowering a group to tackle a problem, based on increased confidence in their knowledge. Other issues, associated particularly with reasons that refer to democratic right to participate, are the assumption of the desire to participate, and the level of focus placed on a topic, dependent upon who chooses to become involved in a process. By inviting stakeholders or members of the public to participate, practitioners are allowing them to shape the focus of a project. This can be very constructive if the remit of the project is flexible, but can

be problematic if specific goals are to be met. When using higher level participation such as PAR (see Section 1.5), the overall aim is often set by a group of concerned citizens with a specific cause, in such cases, organisations, researchers etc. should hold limited or no power within the process, which should be equitable for all involved. This is often an uncomfortable position for organisations who may feel obliged to oversee the process and can lead to power struggles, and problems in communication (Cook *et al.*, 2011). In addition to this, power relations will exist in any participatory process (Cooke and Kothari, 2001) and will, in some way, influence the outcomes. This should be acknowledged and considered as part of the analysis.

Participatory research was considered to be an appropriate approach for this project because of the level of flexibility available in topic and methodology selection, and because the aim was to consider innovative approaches to river research and management. The suitability of a participatory approach, with particular reference to the type of participation used here (PAR) is discussed in Section 1.5.

1.3.2 Levels of participation in river management

As mentioned above, to generate or co-produce knowledge with a diverse group of actors requires a high level of participation and there has been debate over the appropriate level of involvement in river management. Currently, there is widespread use of the term ‘consultation’ within environmental management to cover a number of aspects of participation. However, Antunes *et al.*, (2008) suggest that a process of consultation (as defined in Table 2.3) falls short of including the interests, perceptions and values of the affected parties and that other tools are necessary to promote participation and deliberation in the context of the Water Framework Directive (WFD), which is the driving force for most major catchment management initiatives in the EU at present (see Section 1.2.2). Similarly, House (1999) suggests that the traditional method of ‘consultation’ favours the ‘objector’ and ignores the ‘silent’ member – i.e. there is not a fair representation of all of the interested parties. By their very nature, rivers are multifunctional and therefore it is likely that there will be conflict over their use and management. Using a more integrated participatory process, one in which relationships and trust are built over time, will give the ‘silent’ members greater chance to express opinions and concerns and to share knowledge, ultimately leading to a more democratic process, one of the primary goals of participation.

Therefore, a higher level of engagement has been suggested as necessary for effective and just catchment decision-making processes (e.g. Henriksen *et al.*, 2009). This higher level approach may involve affording participants more control in decision-making, and the creation of new

knowledges and understanding about a system or process. Johnson (2009) suggests that by involving those who affect, and are affected by, the watershed, public values can be incorporated into decision-making, helping to resolve conflicts and qualitatively validate models through knowledge of what the outcome is expected to be. Similarly, in the development of a framework for the evaluation of participatory research in sustainability, Blackstock *et al.* (2007) promote a shift from the traditional 'linear transfer' of knowledge, to the *co-production* of knowledge among a group of interested parties. They believe that, ideally, this should lead to social learning in which people come to understand 'their own and others' interests, values, experiences, beliefs and feelings, and through this understanding, acting for the collective good' (Webler, 1995). In this way, participatory research should empower the participants rather than just provide information to the researcher (Blackstock *et al.*, 2007). By addressing concerns and working with a range of interests, the complexities of a system can be defined and accommodated within the development of solutions. It is this higher level of participation that is examined through the present research process, in order to address questions about its applicability, practicality and effectiveness for river research and management. The study approach is discussed fully in Section 1.5.

1.4 Legislative framework

The importance of public engagement in river management has been recognised not only within the academic context, but also within management practice and legislation. Legislative attempts to situate participation as a fundamental aspect of environmental management include Agenda 21, the UN Conference on Environment and Development (Earth Summit, Rio in 1992), Principle 10 (UN), the European Water Framework Directive, the Federal Clean Water Act (Carr *et al.*, 2012) and the 1992 Dublin Principles (Cook *et al.*, 2011). In the UK, there are a number of legislative guidelines and conventional agreements, operating at different scales, which are used to guide the practice of public and stakeholder involvement. The Aarhus Convention (1998) outlines principles that should be followed when involving others in policy decision-making, and the EU Water Framework Directive (EC, 2000) provides guidance to EU members on the level of involvement required when managing the catchments and waterways of Europe. Within England, DEFRA and its subsidiary, the Environment Agency, are responsible for the development of management strategies for England's rivers.

1.4.1 The Aarhus Convention

The Aarhus Convention (1998), ratified by the United Kingdom along with a number of other European countries, aims to draw a link between *environmental* and *human* rights and proposes that sustainable development can be achieved only through the involvement of *all* stakeholders (UNECE website: <http://www.unece.org/env/pp/>). It is based on the principles of the right to *know*; the right to *participate*, and the right of *access to justice*. The Economic Commission for Europe's guidelines on public participation (1996) inform the priorities of the Aarhus Convention and can be summarised as:

- States should encourage and facilitate the involvement of public and stakeholders in the decision-making process that have environmental implications, particularly at local and regional scales
- Consultation should begin early in the decision-making process to allow public and stakeholder views/knowledge to be incorporated
- The decision-making process should be transparent and information relating to the issue should be accessible to the public/stakeholders
- Explicit rules governing certain procedures should be in place to aid participation

These guidelines have been carried through into specific environmental management legislation, such as the Water Framework Directive, in order to enhance the process in terms of both the environmental and the social outcomes.

1.4.2 Water Framework Directive

The EU Water Framework Directive (2000/60/EC: EC, 2000) is the current driver for most river and catchment management within the UK and the rest of the EU. It is generally agreed (e.g. Welp, 2001; Henriksen *et al.*, 2009) that part of the difficulty in encouraging deeper public involvement is that the WFD explicitly states the requirement of increased public and stakeholder involvement in management decisions but does not describe how, and exactly at what level, this should be undertaken:

“Member States shall encourage the active involvement of all interested parties in the implementation of this Directive, in particular in the production, review and updating of the river basin management plans. Member States shall ensure that, for each river basin district, they publish and make available for comments to the public, including users:

- (a) a timetable and work programme for the production of the plan, including a statement of the consultation measures to be taken, at least three years before the beginning of the period to which the plan refers;
- (b) an interim overview of the significant water management issues identified in the river basin, at least two years before the beginning of the period to which the plan refers;
- (c) draft copies of the river basin management plan, at least one year before the beginning of the period to which the plan refers. On request, access shall be given to background documents and information used for the development of the draft river basin management plan.” (EC, 2000)

Furthermore, emphasis is placed on organisations allowing the public and stakeholders to voice opinions on policies and management plans, but the final decision is very much the property of the competent authorities (in England, this is the Environment Agency). Further compounding the complexity is the increase in recent decades in the call for high-level participation in river management, but with relatively little guidance on approaches to take, or appropriate levels of involvement for various tasks and goals. Organisations, therefore, are left to make a judgement which will inevitably be based around resource constraints (e.g. time, funding), as to how to involve people and incorporate ‘lay knowledge’.

1.4.3 Current UK governance practice

As the English competent authority for the implementation of the WFD, the Environment Agency (EA) is required to provide a clear and transparent process in the development of catchment and river basin management strategies. The current approach to public participation is outlined in a paper by Orr *et al.* (2007), the authors of which are all EA employees, with different personal levels of involvement with the public.

It is acknowledged that as a system becomes more complex, so does the management of it and developing sustainable and efficient plans will require a *joint* understanding of the management problems and potential solutions as well as an effective *co-delivery* of jointly agreed solutions (Orr *et al.*, 2007). Orr *et al.* (2007) note that they have come to recognise ‘that for integrated catchment management to work, we [the EA] need to work with stakeholders’. To achieve an integrated approach, the EA has made a number of ‘arrangements’ on which they will base future stakeholder engagement plans. These operate at a number of scales ranging from national to community:

- **National:** Involves national stakeholders in policy making. Existing example – the WFD stakeholder group set up by DEFRA
- **River Basin District:** Will form a cohesive liaison panel consisting of agencies and institutions with statutory powers to develop and implement RBMPs
- **Catchment:** Stakeholders will belong to ‘catchment frameworks’ in which most catchment planning will be carried out. Examples include Coastal Fora and Rivers Trusts
- **Community:** Discussion will be with individuals and local networks. Problems and solutions will be discussed with local communities. Proposals/outcomes from this tier will be fed upwards

It has been suggested that *early* involvement is the key to effective catchment management (e.g. Eden, 1996; Reed, 2008). Although the proposals of the EA go some way to improving communications with the public, there seems to be limited focus on the actual empowerment of local/lay/public participants. Emphasis appears to remain on ‘representative’ stakeholders and organisations. This study explores the merits and limitations associated with communication which extends to the full involvement of local/community members and individuals.

It is evident that river management approaches can no longer be dictated by researchers or organisations without due consideration of public opinion and impact. In order to fully address both the physical and the social implications of river management, expertise consisting of a variety of disciplines, and a variety of origins, must be accommodated. However, despite the legislative calls for participation, such as those from the WFD and Aarhus, and the provision of guidance documents (e.g. WFD Guidance Document no. 8: EC, 2003), there is limited guidance available to organisations regarding the level at which participation should be carried out, the processes which should be used, or who should be involved (e.g. Henriksen *et al.*, 2009). Furthermore, particularly in management organisations, the benefits presented in the case for participation are primarily environmental or organisational. Some critical questions, therefore, arise from current participatory approaches and have been used to shape the focus of this study. These include: how is participation currently used in river management? Should participation be universally applied? Is it always relevant or are there situations in which it is unnecessary? Whose interest does it tend to serve? And, should the aim always be to achieve the highest levels of participation? These questions will be carried through to the study approach (Section 1.5) and the overall research questions (Section 2.6).

1.5 Study approach: participatory, interdisciplinary research

The research approach for this study is based on the above questions, which have arisen from the legislative requirements for participation (combined with inadequate guidance of how to carry out participation), and on the recent calls within both academic literature and river management policy for a heightened level of involvement, particularly by those with a personal concern, or who are affected by a research/decision-making process. The overall aim is to assess the role of public involvement in creating and/or collecting knowledge about river processes. This is done via two approaches: i) reviewing organisational practice and approaches to participation, and ii) conducting a participatory investigation with a group of interested citizens to address a river management issue. PAR emphasises the action and outcomes which occur as a result of the research (Pain and Francis, 2003) and it is suggested as the appropriate research approach for the latter of the above aims for two reasons: (i) it is to be applied within a UK context (PAR has been formulated in developed countries (Pain, 2004), rather than Rapid Rural Appraisal and Participatory Rural Appraisal, which were formulated in developing countries: see Kesby *et al.*, 2007 for a discussion of the origins of participatory research), and (ii) the main aim of the project is to explore emerging forms of river management that can be designed and influenced by those who live with the impacts from day to day. An interdisciplinary approach is also considered vital for this study in order to allow the amalgamation of traditional social and physical aspects of and approaches to research, to produce outcomes which are relevant and tailored to the issue under investigation. The following sections outline the principles which underlie participatory research and further explain the reasons for adopting such an approach in the context of this study. The epistemological and practical relevance of the interdisciplinary nature of this study is also outlined and the way in which all the research approaches have been combined is demonstrated.

1.5.1 Participatory action research

Defined by Wadsworth (1998), PAR is a process that *'involves researchers and participants working together to examine a problematic situation or action to change it for the better'*. Participatory research should distinguish itself from traditional methods of research, not only through the involvement of members of the public, but through the *action* it instils. Participatory research stands out from traditional methods of social research, which have been criticised for their distant and impersonal approach (e.g. Kesby, 2000; Breitbart, 2003; Pain and Francis, 2003; Cahill, 2004; Cameron and Gibson, 2005). For example, Kesby (2000) suggests that 'conventional' methods of research 'use an externally developed research design, proceed with the extraction of data and ... terminate in the presentation of results in scholarly journals'. As a result, the participants, or subjects, of such research processes can be left to feel excluded and resentful of

the process, with the results failing to achieve more than an academic article or, at best, a policy document (Kesby, 2000). Participatory research aims to address such shortfalls through a number of underlying themes or principles, which take priority over the details of methodology and the process can be seen more as 'an orientation to enquiry' (Reason, 2004), than a structured methodology. The underlying principles are outlined below:

(i) *Full involvement of all participants at every stage, including the development of research questions.* As noted by Breitbart (2003), the goal of PAR is to democratise research design with the full engagement of those affected by the issue. Within PAR, it is believed that there are a 'plurality of knowledges' (Kindon *et al.* 2007, 9) and that the local people affected by the issue in question possess equitable knowledge to the 'experts' who are investigating and therefore there is potential for all parties involved to both educate and to learn (Breitbart, 2003; Kesby *et al.*, 2005; Kindon, 2003; Pain and Francis, 2003). It is the combination of both local and scientific (for the purposes of river management) knowledge that will lead to a result tailored specifically to the needs of the community participating. By developing research questions with the participants in this study, the research topic can be focused, relevant and appropriate to those involved.

(ii) *Empowerment of the participants to effect change through the research process* (Kindon *et al.*, 2007, 1). It has been widely acknowledged that by developing ideas as a group, participants may be enabled to articulate emotions and build confidence in their knowledge, and through this they can become 'empowered', having the ability to bring about changes as a community, for the community (as found by a number of authors including: Cahill, 2004; Cameron and Gibson, 2005; Lane *et al.*, 2011). The process of participation in this study is hoped to enable the participants to raise issues with those in power, such as the Environment Agency.

(iii) *Focus on the changes that can be brought about by the involvement of all, rather than only the 'academic outputs', i.e. action.* As Pain and Francis (2003) have noted, participatory research 'demands more in terms of achieving change than simply presenting findings into the public domain' and Cahill (2004) suggests that research should be seen as a 'vehicle for social change' (rather than a means to an academic publication). Although there are different attitudes to how exactly the produced knowledge should be used, what is accepted is that the sharing of local knowledge is necessary as the first step towards social change (Mohan, 1999). Therefore, the empowerment and subsequent action of communities as a result of participatory research could be considered as the next steps towards social change. However, achieving this aim is not without its problems, and these will be discussed later.

(iv) *A non-linear or flexible approach allows the participants to lead the project.* Some of the literature surrounding PAR is concerned less with the actual methodology of the process than the ideology and politics of the approach (Breitbart, 2003) because true PAR cannot be divorced from its philosophical basis of knowledge production *by* and *for* the non-elite. Additionally, the methods used vary greatly according to factors such as the issue being investigated, the range of knowledge and experience possessed by each of the participants, including academics and organisations, time available etc. This detail also allows for a good degree of flexibility within the PAR process. This is important because it enables the outcomes of the project to influence the direction of subsequent discussions and actions – allowing the participants to lead the project. This, as highlighted by Breitbart (2003), can ‘generate new questions, issues and strategies that build upon a deepening understanding of an issue or topic’. It is building on these questions and strategies, as well as the longevity of the approach, that allows projects and potential solutions to develop (e.g. Pain and Francis, 2003) and participants can begin to feel confident and empowered by breaking down the barriers between ‘academic’, ‘political’ and ‘local’ approaches, feeling competent enough to challenge the science, and discussing issues with which they are familiar and comfortable.

The four principles discussed above are highly relevant to the situation of river management in the UK (and most of Europe) at present. It has been widely published that river management approaches should be reflexive, account for (and value) less traditional forms of knowledge, focus on the outcomes and applications and be achieved through a process which allows participants to use their own knowledge within the investigation, and beyond it. Additionally, participatory research, when successful, should be context-specific and should forefront local knowledge, thus leading to ‘situated, rich and layered accounts’ (Pain, 2004). These factors have been expressed as fundamental for river research and management which is both scientifically and socially accountable. Therefore, a participatory approach to river management and research seems appropriate. However, the benefits of participatory research are conditional upon a number of criteria, and with specific reference to river management, these have been cited as: the acceptance of accountability by each party; strategic and forward planning to anticipate issues; vision, leadership and structure to keep the process running smoothly; relevant stakeholders or participants, including less vociferous members of the community; adequate definition of the issue in order to guide the process and evaluate its success; adequate information on which to base decisions and appropriate communication mechanisms to make that data accessible to all involved; respect for local knowledge and workable solutions that are expressed and

communicated clearly and succinctly (Bowden *et al.*, 2004). This study will further explore the proposed benefits, and some potential limitations.

1.5.2 Limitations and dangers of a participatory approach

As mentioned, there are of course limitations to the approach, many of which are in some way linked to power relations. For example, there may remain, to some degree, certain members of the community who feel they are unable to voice their true opinions/concerns (Breitbart, 2003; Cahill, 2004), as well as members who will portray knowledge in a way that is designed to gain personally, even though this may not be the aim of the community as a whole. Related to this, there may be a conflict of interests between participants (Breitbart, 2003) which can inhibit productivity if it is not solved. The situation in which the research is conducted (e.g. group sessions, highly emotional topics) is likely to affect the way in which information is relayed (as found by Pain and Francis, 2003) and therefore issues may arise associated with power balances, and the interpretation of information. Indeed, due to the flexible and non-structured approach adopted, data may be generated in a number of forms and may be very difficult to analyse or quantify, and may be biased towards the strongest members of the group. Participatory research requires the researcher to commit enough time to the investigation and to the group, to see through all stages in order for the process to be empowering and support equitable change (Kindon, 2001). The process will only be of benefit to the group if they are able to utilise the outcomes (whether these be knowledge created about the river, or social developments).

When participation is carried out by or for a management organisation, the power to implicate change may not ultimately lie with the participants and/or academics and Mohan (1999) notes that an improvement in policy does not necessarily lead to an improvement in practice. Therefore, the aim of the research may not be fully achieved (Pain and Francis, 2003). Researchers/facilitators should be realistic and take due care to manage expectations. In addition to a lack of final power, there is the potential for abuse of the approach by organisations who conduct the research in name only, implying that they have 'consulted fully' but not actually allowed sufficient *participation* (Kindon, 2001; Pain and Francis, 2003). Although many river managers claim to practice high-level participation, it is common to find that it is carried out solely to allow a practitioner to claim that it has been done, and this can be more detrimental to a research project, or to community engagement, than not having involved people at all. If participatory and deliberative processes do not have clear goals, (besides the goal of having them), it should be expected that their outcomes will be partial and irrelevant to decisions (Antunes *et al.*, 2009). In other words, the formulation of clear goals and actual outcomes are

essential to progress from a research or management exercise into a process leading to environmental improvement.

The principles behind participatory research make it a suitable approach for involving external participants and generating knowledge for river research and management. However, it requires careful planning and considered, reflexive execution in order to be truly effective. This study also requires the integration of a number of traditional research approaches and an interdisciplinary attitude to the process.

1.5.3 Participatory approaches in river research and management

Participation for river research and management is quite widespread, but approaches that constitute co-production are not. However, there are some examples of studies utilising a higher-level approach. The most relevant example is that of PAR work on the River Lune (Pain *et al.*, 2012), in which a process of planning, action and reflection (recurrent until outcomes are satisfactory) and evaluation, was used to address issues and instil knowledge generation between academics, a rivers trust, and members of the public, on the River Lune. The co-produced 'PAR Toolkit' (Pain *et al.*, 2012) provides guidance through the phases of PAR for those wishing to employ the approach, with examples drawn from the Lune project. Other published accounts have been more closely focused on case studies and their specific outcomes. Lane *et al.* (2011) used PAR with a group of residents to develop an understanding of the flooding events within a small town and develop management options which the group, buoyed by the confidence and knowledge built through the process, were able to use in flood protection negotiations with the Environment Agency. While Hansen and Maenpaa (2007) review the challenges associated with participation in river management, a number of authors have presented positive outcomes of participatory practice (e.g. Edward-Jones, 1997; Welp, 2001; Clark, 2002; Antunes *et al.*, 2009; Henriksen *et al.*, 2009). However, while achieving their stated goals, within these case studies the participatory approaches used often fail to fully involve participants to the level such that 'true' PAR can be achieved. The characteristic of working with a group who are sufficiently concerned about an issue to move them to act upon it is often missing from these studies and broad goals have been set prior to the participatory process (this is likely related to the management/policy nature of the studies, there are few studies which use PAR primarily for the benefit of the participants or to simply learn about catchment issues and processes, but those that do exist include Bowden *et al.*, 2004; Lane *et al.*, 2011). This study therefore, aims to assess the productivity of a PAR process (both environmentally and socially) when a concerned group is engaged and research objectives are developed as an integral part of the research process. In addition, the Organisational Review has been used to provide context for the relatively

unrestricted Ebchester Study and to identify differences in constraints for different organisations, as well as their implications for the participatory process.

1.5.4 Epistemological approach and the role of interdisciplinarity in environmental research

There is increasing recognition of the need to address management problems in an interdisciplinary way (e.g. Bowden *et al.*, 2004; Blackstock *et al.*, 2007; Antunes *et al.*, 2009) and to comprehend that biological, physical, social and economic components of management are not separate issues but must be considered and addressed as a complete system. Bowden *et al.* (2004) discuss the necessity for integrated research which covers not only biophysical and ecological but also social, economic and political mechanisms. In doing this, a new approach to knowledge transfer must be adopted in which science providers, resource managers and stakeholders interact through shared learning and adaptive management (Allen *et al.*, 2002). Blackstock *et al.* (2007) support the opinion of Bowden *et al.* (2004) that bio-physical processes must be considered in their socio-economic context. This requires input from a range of disciplines in order to determine the true impacts of a change in process – or as Blackstock *et al.* suggest: ‘sustainability science contributes to socio-political decision-making processes through information provision derived from emergent interdisciplinary inquiry’ (Kasemir *et al.*, 2003). With application to the WFD context, interdisciplinary working is considered to be important and requires involvement of participants from a range of backgrounds because most elements of the WFD encompass technical, ecological, economic, legal and administrative aspects (Antunes *et al.*, 2009). This study aims to address the hydrological, ecological and societal aspects of the river research process and determine to what degree PAR can assist in understanding and balancing the needs of all.

The nature of the present study requires it to focus upon two very different, even contrasting, types of environmental knowledge. These are *scientific* knowledge – attained from physical data concerning the characteristics of the river, which may be on a reach, sub-catchment or catchment scale; and *experiential* (or ‘lay’) knowledge, which is possessed by those who live with the river on a daily basis and is more likely to be detailed on a small area (e.g. in the stretch in which they prefer to fish, or the stretch that runs through their land). The aim here is to facilitate communication of these different types of knowledge in order to lead to the *co-production* of a new knowledge. The merits of interdisciplinary research and the integration of the social and physical aspects of geography have been debated, (e.g. Goudie, 1986; Nissani, 1997; Brewer, 1999; Hansson, 1999; Wear, 1999; Gregory *et al.*, 2002; Lane, 2001; Harrison *et al.*, 2004; Lawrence and Depres, 2004; Ramadier, 2004; Bracken and Oughton, 2006; Lane *et al.*, 2006). It

has been suggested that interdisciplinary studies are often viewed as superficial (Goudie, 1986; Brewer, 1999) and their benefits can be misunderstood (Nissani, 1997). Bracken and Oughton (2006), while in support of interdisciplinary research, acknowledge that there are difficulties, including differences in epistemologies. Despite the limitations experienced, there is strong support for an interdisciplinary approach to environmental research. The dominant argument in favour of interdisciplinary studies is that because human and physical environments do not exist independently of one another, when managing either aspect, both arenas must be considered (e.g. Goudie, 1986; Gregory *et al.*, 2002; Harrison *et al.*, 2004). It has been suggested that interdisciplinarity can be used to obtain coherence between different disciplines and develop a new, single form of knowledge (Ramadier, 2004), while Milgram (1969, 103) proposed that 'intellectual cross-pressures generated by an interdisciplinary outlook...stimulate fresh vision' and Nissani (1999) prescribes the promotion of interdisciplinary knowledge and research to those who wish to speed up the growth of knowledge. These benefits link back to the goals of a participatory research approach and in response to these observations, the purpose of this project is to create a new knowledge through the fusion of contrasting knowledges.

River management and the role of participation are high on the agenda of environmental research. However, due to the complexity and range of applications, there is little guidance to the optimum approach, particularly in finding the correct balance between achieving goals and developing public engagement. As discussed above, the importance of public participation in planning for river restoration activities is a growing concern. Indeed, Immerwahr (1999) suggests that the social sciences are under-represented in restoration science, while Junker *et al.* (2007) advise that an investigation into the 'effect and efficiency of different forms of public engagement' is necessary to optimise the decision-making process in river management. It is in response to this, and in pursuit of achieving an appropriate level of public involvement, in order to investigate the proclaimed benefits of high-level participation and associated outcomes (such as the co-production of knowledge), that PAR is proposed as a suitable approach for developing ever popular river management strategies.

1.5.5 Frameworks used within this study

The above sections highlighted the importance of an inclusive approach to decision-making for environmental management. Therefore the participatory approach is incorporated as the central framework of this study, and will be supported by a secondary framework of interdisciplinarity. Together, they will draw together the social and physical aspects of river restoration as one unified process which seeks to utilise experiential knowledge and empower those in possession of such knowledge. Furthermore, the project aims to investigate the effectiveness of the 'co-

production of knowledge' approach (as outlined by Callon, 1999, see Section 2.3.6) within this framework to determine whether it is as valuable in practice as in theory. Figure 1.2 demonstrates how the individual components are brought together.

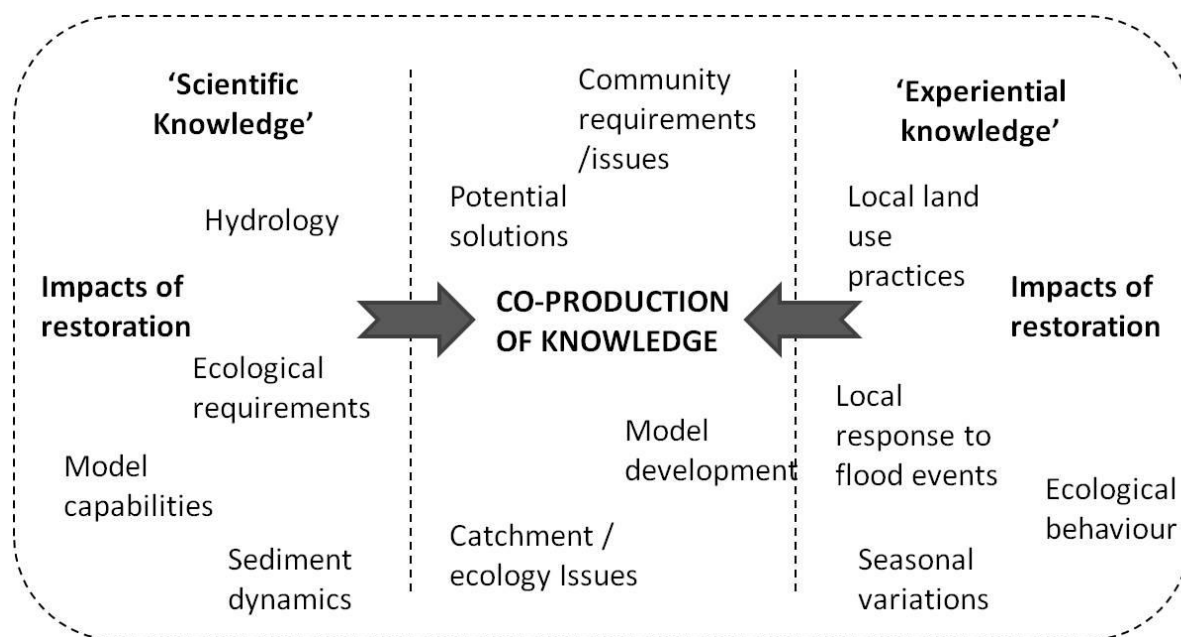


Figure 1.2 Unity of 'scientific' and 'experiential' knowledges for the co-production of a new, holistic knowledge. The different types of knowledge are offered by different members of the group, but within the context of the competence group, are re-formulated and produce a new knowledge and a new understanding of the process or issue. The examples in this figure are based on the topic of research that was chosen by the competence group for this study: the impact of weir restoration on the surrounding river reach

1.6 Thesis structure and presentation

1.6.1 Structure

This thesis aimed to utilise both social and physical approaches and methods of geographical research in order to develop a learning approach in which all aspects of relevance were addressed, and categorisation of research according to traditional standards was avoided. This chapter has set out the approach to achieving this (a participatory and interdisciplinary study of river processes and management, and the social and environmental impacts). Due to the participatory nature of this study, the ultimate research topic was established as part of the participatory process. Therefore, research questions for the overall process are presented following a review of the relevant theories and case studies within the field, and the objectives for

the topic of river research were established only once a group of interested individuals (the competence group) had been assembled (and are therefore not presented until Chapter Five). The thesis has been organised into four parts : i) theoretical frameworks and context; ii) review of organisational practice; iii) interdisciplinary participatory research, and iv) synthesis. The first part sets the context and rationale for the study with a review of current literature, as well as outlining the details of the methodological approach. The second part provides a review of current river management and participatory practice for a number of organisations (OROs: Organisations specifically involved with the Organisational Review) in the UK and north-west Europe. The third part introduces the interdisciplinary approach adopted in order to address the above aim, combining hydraulic modelling with a number of social research methods in order to establish an appropriate and context specific research project, and to address a number of research objectives relevant to a competence group. Finally, all aspects of the research are drawn together to assess the role of high-level participation and knowledge co-production in a number of varying river management situations. The dominant factors affecting the success of this approach, and the relevant success of the study are discussed.

1.6.2 The chapters

Part I: Theoretical framework and context

Chapter Two: The current state of knowledge, participation and river management. Introduces the theories and case study findings which have shaped the framework of this study. These include changes in modes of knowledge production, the role of knowledge co-production and knowledge controversies, levels of participation and the strengths and weaknesses of participation in river management. The chapter is concluded with the research questions for the study.

Chapter Three: Methodology. This chapter outlines the methodology of the overall study, highlighting the aim of each of the subsequent stages and describing each methodological step in turn, offering justification and context for each method choice. It outlines the process followed in establishing the research topic for the thesis and assembling a competence group to investigate that topic. The focus in this chapter is based on the overall approach and therefore discussion of social research methods dominates. A detailed description of the physical research approach is given in Chapters Six and Seven.

Part II: Review of organisational practice

Chapter Four: The Organisational Review: approaches and barriers to participation in river management describes the results of the review of organisational practice and considers them in

the context of knowledge production theory (primarily that of Callon, 1999). The main constraints on participation for river management organisations are presented and the potential for participation to be used as a resource is discussed.

Part III: Interdisciplinary research approach

Chapter Five: The Ebchester Study: context and process. This chapter describes the physical and social characteristics of both the Derwent catchment and of the reach around Ebchester Weir: the chosen study site. This includes a description of the knowledge, questions and issues that the local community have about the weir area and fluvial processes, which were obtained through a number of competence group meetings. The information gathered in the competence group meetings culminates in a set of research objectives for the competence group, and is followed by a review of the theoretical implications of channel impoundment and management.

Chapter Six: The fundamentals of hydraulic modelling are outlined in this chapter, which presents some of the fundamental aspects of the physical representation of flow in an open channel, which underline all hydraulic modelling research. The different modelling approaches available to researchers were discussed. The modelling process required in any fluvial research context was outlined and the chosen approach was justified in the context of the aims of this study.

Chapter Seven: Hydraulic modelling of the River Derwent. The process of model development, testing and application of the River Derwent and the Ebchester Weir reach are described in this chapter. The results based on the competence group's research objectives are presented, with focus on predicted impacts of changing weir profile for water level, sediment dynamics, and vegetation removal from a mid-channel bar.

Chapter Eight: Case study findings, integration of knowledge and final model outputs. In this chapter, the response of the competence group to the preliminary model outputs is presented and discussed. Model developments, based on this response and on experiential knowledge and prioritisation of topics, are outlined and the final river research results are presented. The implications of these results are discussed within the context of both academic knowledge of river processes and the knowledge provided by the competence group at various stages of the process.

Part IV: Synthesis

Chapter Nine: The role of participation and knowledge co-production in river management. This Chapter draws on the findings from all stages of this study, including the organisational practice review, the establishment of a competence group, and the application of hydraulic modelling in

this context. The chapter includes a critical review of the participatory process and of the continued pressure to involve participants in every research project. This is linked to both practical case studies and to knowledge creation theory. Three main constraints to participation and knowledge production, which were identified within this study (scale, validity of knowledge and participant apathy) are discussed, and their implications explored. The benefits of participation that were identified by the study and the merits of using hydraulic modelling as a participation and research tool are discussed. Some final questions are discussed and the lessons learned from the process are presented.

Chapter Ten: Conclusions and study implications. The main findings of the study are summarised and the implications of these findings are discussed for river management, for participatory research and for the development of future approaches to river research. Outstanding questions and topics for further investigation are highlighted.

This chapter has set the context for participation as a fundamental aspect of river management and has situated participatory and interdisciplinary research as the appropriate approaches for investigating participation in river system knowledge production. Chapter Two, as described above, introduces the theoretical frameworks and practical case studies which highlight the role of participation and knowledge generation in hypothetical and practical river management contexts. The review of literature on this topic leads into the presentation of research questions for this study.

Part I:

Theoretical frameworks and
study context

Chapter Two

The current state of knowledge, participation and river management

2.1 Chapter themes

Chapter One introduced the issues of catchment management in the UK and discussed the roles of participatory and interdisciplinary research in addressing fluvial issues. In this chapter, a framework will be established for the topics of this thesis.

This chapter is ordered according to three key themes for participation in river management. First, past and current approaches to river management and the changing role of knowledge in such approaches are outlined. The second theme considers the various modes by which scientific knowledge is produced, and how it could be utilised. Finally, a critical review of the role of participation and knowledge in the river management context is presented and the focus of this study positioned within the knowledge frameworks discussed.

The first theme (Section 2.2), describes the change in recent decades in how rivers are managed, from a hard engineering and scientific approach to a soft engineering approach which utilises the resources and knowledge available locally to the river and aims to 'work with' the river, rather than control it. This leads into a discussion of the way in which participation has become a popular recommendation for river management and the heightened public interest. The second theme (Section 2.3) outlines a number of frameworks based on the changing modes of knowledge production, which have been increasingly popular in Science and Technology Studies, and the relevance of which extends to river research and management. Central to the new, democratic, inclusive and socially responsible modes of knowledge production is the concept of knowledge co-production. The principles behind this, and the requirements for its successful achievement are outlined in this section and their importance for river research are discussed. The final theme

(Sections 2.4 and 2.5) encompasses the benefits and limitations of a participatory process (at a number of levels of involvement), specifically for river research and management. In this section, the processes followed in order to achieve new knowledge of the river environment are critiqued. The chapter concludes (Section 2.6) with questions that remain unanswered concerning the role of participation in river management and how these have steered the research questions for this study.

2.2 A brief history of river management approaches

Traditionally, the approach to river management has been anthropocentric and utilitarian (McDonald *et al.*, 2004), technical and focused on hard engineering solutions and flood prevention. In recent years (and predominantly in the 1990s: Adams *et al.*, 2004), in response to a re-definition of catchment goals (e.g. the move away from the naturalisation of rivers, see below) and under new legislative controls (e.g. WFD), this has changed to an approach that considers restoration or rehabilitation with ecological concerns, soft engineering, and input from a more diverse group of participants (Petts and Calow, 1996; Downs *et al.*, 2002; Adams *et al.*, 2004; McDonald, *et al.*, 2004; Newson and Chalk, 2004; Tippett *et al.*, 2005; Pahl-Wostl *et al.*, 2007). Sear *et al.* (1995) note that (hard) engineering as a tool to control the river environment has dominated in the UK for the past three hundred years and has been recognised by ‘politicians and the aristocracy’ as worthy of investment and trust. In the restoration context, usual practice was originally to aim for the ‘naturalisation’ of rivers (Adams, 2003), but Newson and Large (2006) propose that softer, more interdisciplinary approaches which aim for states of geodiversity are more important than aiming for a return to the ‘natural’ state (which itself is almost impossible to define, see Elliot, 1997). The change in management focus has resulted in an increase in the number of groups involved in the management process (Sear *et al.*, 2000).

Further to the shift from technical hard engineering and fixed solutions, towards a softer, more interdisciplinary approach, there has also been a switch from a top-down (or ‘downstream’) (Rhoades, 1998) to bottom-up (‘upstream’, or at the very least, more evenly distributed) approach to river management. Reinforcing this was the role of the technical experts, whose exclusive task it was to manage river systems under the auspices of the state (Pahl-Wostl *et al.*, 2007).

Participation of the public in environmental planning has existed for over 50 years, when in the 1960s, authorities provided information in the form of brochures and meetings to involve the citizens (Hansen and Maenpaa, 2007). However, this uni-directional flow of information persisted until the 1990s. In recent years, there has been a change in the style of the relationship between

the public, science, technology and the environment (Beck, 2005; Henriksen *et al.*, 2009). As Pahl-Wostl *et al.* (2011) note, in past decades, river management has been an activity exclusive to 'technical experts' and involvement of those outside of this realm was severely limited. In 1996, Eden suggested policy still assumed that education of 'non-experts' would be enough to effect behaviour change. This is no longer satisfactory, based on the democratic right of those who are affected by decisions to be involved, and has been highlighted, for example, by the underlying principles of the Aarhus Convention (see Chapter One). In response to these societal changes and with the dawn of modern environmental directives, such as the Water Framework and Habitats Directives (see Section 1.4), as well as the efforts of a number of restoration 'champions' (Adams, *et al.*, 2004), and developments in communication technologies and Geographical Information Systems (GIS) (Hansen and Maenpaa, 2007), information is now more readily available to non-experts (Newson and Chalk, 2004). Discourses to institutionalise participation to extend beyond the involvement of solely traditional technical experts is also prevalent in international legislation, and has been highlighted in a number of legislative acts such as Agenda 21, the UN Conference on Environment and Development (Earth Summit, Rio in 1992), Principle 10 (UN) and the 1992 Dublin Principles (Cook *et al.*, 2011), as well as emerging independently in legislation in the United States (Sabatier *et al.*, 2005) and Australia (e.g. Healthy Waterways, 2010: Cook *et al.*, 2011). The improved access to information and the attention brought about by such legislation to the importance of bi-directional communication, has resulted in an increase in public interest in the processes of river and catchment management. Members of the public are no longer satisfied with sitting back and allowing 'the professionals' to make decisions which will ultimately affect them. There is now a 'public demand within new polities to express quality of life aspirations' (Newson and Chalk, 2004) and public participation in environmental decision-making is increasingly considered as a democratic right (Reed, 2008).

Although the recent improvement in access to information has allowed non-experts to develop knowledge of the science behind the decision-making processes and has increased the level of public interest in these processes, there has been another outcome which has changed the relationship with the public and 'science'. With increased comprehension or access to information, comes increased questioning and in many cases this has resulted in a shift in the levels of trust that the public has in scientific processes and outputs. Loss of trust in science is considered to have resulted in a 'crisis of confidence' (e.g. Beck, 1992) because of the demonstrated inability of scientists to 'foresee and control negative consequences of science and technology' (Callon, 1999). Lane *et al.* (2011) note that trusting relationships do not always exist: trust in organisations and river managers is often lost (perhaps through failure to be able to offer

certainty of results, or as a result of conflict between scientists (Callon, 1999)), which leads to scepticism over management practices.

It has been suggested that trust in the knowledge of one another is an essential prerequisite of the effective management of a river corridor (e.g. Henriksen *et al.*, 2009). It is necessary for the development of effective policies, the acceptance of policies and the involvement of certain social groups (e.g. those affected by decisions) in democracy (Enserink and Monnikhof, 2003; Henriksen *et al.*, 2009). Sturgis and Allum (2004) suggest that trust in expert claims is an important defining factor in the context of publics' scientific knowledge (which, under their contextualist theory, affects a person's or community's attitude to science). Scientific knowledge is, by nature, provisional (Wynne, 1992a) and trust in its worth should be (re-)built by allowing those who mistrust it to: (a) examine it for themselves (Yearley, 2005) and; (b) be a part of the generation of that knowledge (and of the research questions upon which it is based). As a result, trust will be a consequence of the total activity of knowledge co-production (rather than an end point). To achieve this requires the *early* involvement of all participants in the process (House, 1999; Welp, 2001; Tippett *et al.*, 2005; Blackstock *et al.*, 2007; Henriksen *et al.*, 2009). Habron (2003) suggests that by dealing with non-governmental and non-regulatory organisations, one can reduce communication barriers between communities and organisations, thus reducing bureaucratic tensions and allowing a more efficient sharing (and production) of knowledge. Firth (1998) and Junker *et al.* (2007) propose that support for process outcomes is highly dependent upon peoples' perception of quality in terms of their own preferences (i.e. if they have a say in policy development, they are more likely to support its products) and an increased level of public participation leads to an increase in trust between the public and practitioners, scientists, etc. Additionally, if a certain viewpoint or opinion is not incorporated into a process, this must be fully justified by those with power and it is hoped that through the participatory process, the reasons for discounting a viewpoint would be reasonable, and acceptable to those presenting it. Sometimes trust between parties (e.g. scientists, practitioners and stakeholders) breaks down. According to Clark (2002), in these events, expert knowledge and stakeholder knowledge have to co-exist. If an approach can be developed that allows the *co-production* of knowledge (i.e. a fusion of separate knowledges that leads to a new understanding of the system), then management and restoration approaches could have much greater impact and be more sustainable. Focus will return to this topic in Section 2.3.6.

It has been suggested that public scepticism in science (Reed, 2008; Pahl-Wostl *et al.*, 2011), combined with increasing knowledge and interest in environmental decision-making (termed by

Irwin, 1995, as 'citizen's science') (Reed, 2008) has driven the acceptance and promotion of widespread participation in river management. Pahl-Wostl *et al.* (2011) argue that the paradigm shift that has occurred in the last 50 years (from technical solutions, towards innovative and participatory approaches to water management) has been partly due to 'an increased understanding of complex systems phenomena and a weakening of the previously privileged role of 'science' in knowledge production'.

The issue of trust in science has led to a re-assessment of the role of knowledge in river management and a process of integrating various forms of knowledge (i.e. not just 'scientific' knowledge) has been widely supported (e.g. Eden, 1996; McDonald *et al.*, 2004; Newson and Chalk, 2004; Pahl-Wostl *et al.*, 2007; Petts 2007; Reed, 2008; Newson, 2010; Slobbe *et al.*, 2010; Oliver *et al.*, 2012; Phillipson *et al.*, 2012). A number of benefits are claimed for the integration of scientific and local knowledges, including an understanding of complex socio-ecological systems and processes, an evaluation of proposed solutions on a local basis (Reed, 2008), a holistic view of environmental problems, provision of long-term, in-depth local knowledge and an identification of individual and community needs (McDonald *et al.*, 2004). The intense and contextual local knowledge possessed by lay people, which can act as the learning driver in deliberative engagement (Petts, 2007) has been quoted as one of the main reasons for knowledge integration (Wynne, 1991; Harrison *et al.*, 1998; Irwin, 1995). Tippet *et al.* (2005) suggest that in the context of the Water Framework Directive (WFD), the goals are ambitious and will require different groups (such as water managers, stakeholders and local people) to work together and embrace new approaches and changes in behaviour.

The role of knowledge in its diverse forms has been a popular topic of analysis in the last 20 years (as discussed above) and understanding knowledge types, and how they are created will help researchers and practitioners to understand the potential for use in river management. Therefore, the following sections will focus on the changing relationship between science and society, how knowledge production has changed in response to these changing relationships and how this has affected approaches to river research and management.

2.3 Knowledge production for science and society

2.3.1 Types of knowledge production

Co-production of knowledge and participation have been favoured topics within Science and Technology Studies (STS) literature for some time and a number of authors have presented

viewpoints on the role of the processes (e.g. Gibbons *et al.*, 1994; Callon, 1999; Nowotny *et al.*, 2001). There have been a number of attempts to classify different ‘modes’ or processes of knowledge production in science, and those which dominate will be outlined here. Bucchi and Neresini (2008) note that there are a number of studies reporting the advent of a ‘new form of interaction between non-experts and scientific knowledge’, that of *knowledge co-production*, which will be considered in Section 2.3.6. However, first there will be a brief review of the initial state of science and communication which led to a re-assessment of the forms of knowledge production used: the public deficit model.

2.3.2 The problem: the public deficit model

The ‘public deficit model’ (Wynne, 1991, 1995; Ziman, 1991) focuses on the inability of the public to understand scientific concepts and outputs. The public are considered to be ‘deficient’ while scientists are ‘sufficient’ (Sturgis and Allum, 2004), in terms of knowledge and understanding. The cause of this is, in theory, a ‘prejudicial public hostility’ towards science and misrepresentation of scientific output by the media (Bucchi and Neresini, 2008, 450). The solution, therefore, should lie in better provision of information to the public and as a result, the public debate model adopted a linear, pedagogical and paternalistic view of communication, to suggest that communication with (or to), the public should be improved (Bucchi and Neresini, 2008, 450). In the early stages of the model, and around the time of the publication of the Bodmer Report (1985) into the public understanding of science, it was believed that better communication of scientific research results would enhance public understanding, increase support for scientific activity, and allow citizens to democratically assess policy and management decisions. The assumption was that the restoration of the linear flow of knowledge to the public would be the antidote to a loss of trust in science (Callon, 1999; Lane *et al.*, 2011). The model has faced criticism on a number of grounds, however, with Bucchi and Neresini (2008, 451) commenting that ‘the disjunction between expert and lay knowledge cannot be reduced to a mere information gap’. One of the primary critiques of the theory is that people’s dissatisfaction with, or fear of science is based on more than just their understanding of science (such as cultural factors or personal values: Slovic and Peters, 1998; Sturgis and Allum, 2004; Bucchi and Neresini, 2008, 450). There is also uncertainty over how ‘scientific understanding’ should be defined (e.g. Hayes and Tariq, 2000; Peters, 2000). The context of one’s knowledge, of which scientific understanding is a part, will also affect the formation of views (Sturgis and Allum, 2004), a view supported by Jasanoff (2000), Yearley (2000) and Wynne (1992b). Despite these criticisms, and while acknowledging there are limitations with the model, Sturgis and Allum (2004) believe that there may be some worth in its claims, such as the level of scientific understanding may in some way

correspond with the way in which individuals form opinions or make decisions (also noted by Bucchi and Neresini, 2008). This view is supported by the findings of Popkin and Dimock (1970) who report that those with a high level of political understanding find political scandal less serious than those with a shallower understanding (because they can use their knowledge to assess and make their own decisions about the situation). Furthermore, authors such as Beck, and Yearley take a more 'rational and cognitive' view of the environmental debate (Eden, 1996) and Yearley (1991) suggests that the traditional authority of science is imperative because it legitimises the environmental movement.

In response to the many criticisms of the model of the public deficit in scientific understanding, new forms of communication and knowledge production have been explored and categorised, and are described in the following sections.

2.3.3 The solution – a new approach to knowledge production?

The changing mode of knowledge production has been a popular topic of debate in recent decades. A number of knowledge production processes have been presented (some described, some prescribed). Those which dominate discussion are outlined in the following sections.

2.3.3.1 The popular theory – Mode 2 knowledge production

The analysis of the change in modes of knowledge production came about following a transformation of the 'funding and organisation of science' in the mid 1990s (Mirowski and Sent, 2008, 667). The book 'New production of knowledge' by Gibbons *et al.* (1994) described the change in research which forced it to be more responsive to external interests and concerns (Mirowski and Sent, 2008, 667).

Mode 2 knowledge generation is suggested to be the optimum approach, for example, it is claimed to transcend disciplines, communicate through dense networks to innovate, and to create tension because standardisation of scientific competence occurs alongside heterogeneous sources of information (Croissant and Smith-Doerr, 2008, 702). Mode 1 knowledge (defined in order to provide a comparison for Mode 2), on the other hand, is 'bounded by academic disciplines, hierarchically organised and separated into discovery or application' (Croissant and Smith-Doerr, 2008). Gibbons *et al.* (1994) define five aspects in which Mode 1 knowledge production (i.e. the long standing traditional methods) differs from Mode 2 (the new approaches, which are growing in dominance). Table 2.1 summarises these transitions.

Mode 1 feature	Mode 2 feature	Description
Academic context	Context of application	M1 knowledge acquires its application after it is created, requiring a 'knowledge transfer', in M2, the knowledge is developed in response to the application itself
Disciplinary	Transdisciplinary	Interaction between disciplines is dynamic and knowledge produced under M2 cannot easily be assigned to one discipline
Homogeneity	Heterogeneity	The location of M2 knowledge creation extends beyond research institutions and is conducted in mutual interaction
Autonomy	Reflexivity/social accountability	M2 knowledge creation acknowledges the value of multiple and diverse views. Makes outputs more socially relevant and considers the impacts of the research
Traditional quality control (peer review)	'Novel' quality control	Knowledge created by M2 is not only accredited by peer review, but by social, cultural or political criteria

Table 2.1 Transitions from Mode 1 to Mode 2 knowledge production. Adapted from Gibbons *et al.*, 1994; Nowotny *et al.*, 2001; 2003 and Hessels and van Lente, 2008

In response to the critique that was applied to the Mode 1/Mode 2 framework, the book 'Re-thinking Science' (Nowotny *et al.*, 2001) was published, which cast Mode 2 as 'a change in the epistemological presumptions of the actors' (Mirowski and Sent, 2008, 667). This new consideration of Mode 2 knowledge production provides a deeper, more considered presentation of the approach, which can be defined under three themes: relation to sociological literature; application of Mode 2 beyond the boundaries of science, and specification of new scientific practices (Hessels and van Lente, 2008). In short, Mode 2 considers a contextualised form of knowledge production in which 'society speaks back to science' (Nowotny *et al.*, 2001, 50) and the outcome is claimed to be socially robust knowledge (Hessels and van Lente, 2008).

2.3.3.2 Triple helix model of knowledge production

In contrast to the formal outlay of the Mode 1/Mode 2 scheme, the triple helix paradigm has grown more sporadically through a range of journal publications, and is championed by Henry Etzkowitz and Loet Leydesdorff (primarily Etzkowitz and Leydesdorff, 1998, 2000 and Leydesdorff and Meyer, 2006). 'Triple' refers to three sectors which are industry, government and academia and the interactions that take place between them and the helix represents the ever tighter converging of the institutions through their connections (Croissant and Smith-Doerr, 2008; Hessels and van Lente, 2008). In the triple helix theory, Etzkowitz suggests that universities have faced two revolutions, "the first being the incorporation of research and teaching functions, and the second being the reconciliation of economic development between those two functions"

(Mirowski and Sent, 2008). 'The organising principle of the triple helix is the expectation that the university will play a greater role in society, as entrepreneur' (Etzkowitz, 2003, 300) and the theory is based on the observation of 'an overlay of reflexive communication between universities, industries and governmental agencies' (Hessels and van Lente, 2008).

There are a number of critics for both the Mode 2 and the triple helix theories. Hessels and van Lente (2008) identified a number of themes associated with the criticisms of Mode 2, which address the descriptive/empirical validity of the theory, its theoretical and conceptual strength, and the political value. Godin (1998) suggests that the distinction between basic and applied research, which Gibbons *et al.* (1994) argue as the basis for Mode 2, has never existed. Godin (1998) also disputes the claim that Mode 2 knowledge is transdisciplinary, suggesting that knowledge production does occur in isolation, but draws on other disciplines. According to Mirowski and Sent (2008, 669), the Mode 2 approach suggests a change in epistemology, rather than focusing on specific actors, while the triple helix approach centres on certain countries and culture areas but is said to fail in providing a coherent analysis and does not sufficiently explore issues of intellectual property. Croissant and Smith-Doerr (2008, 703) suggest that critics of the theories are concerned about the lack of epistemological sensibilities (e.g. how knowledge is constructed) (Baber, 1998) and about them treating knowledge as a 'black box' which can be passed between institutions. Worryingly, Mirowski and Sent (2008, 670) propose that both theories 'simply presume that any marketised science inevitably enhances freedom, expands choice, encourages extended participation and improves overall welfare'.

Although the Mode 2 approach appears to be the most commonly discussed analysis, and is followed by the Triple Helix framework, there have been a number of alternative attempts to classify the changes in knowledge production and relationships between science and society. These are considered below.

2.3.3.3 Knowledge production through Post-normal science

The idea of *post-normal science* was initiated by Funtowicz and Ravetz (1993). The term 'post-normal' is derived from the requirement of a development of 'normal' science research, in which the simplistic division of problems is assumed possible. Traditional methodologies of problem-solving are ineffective when the attributes of systems uncertainties and decision stakes are high (Funtowicz and Ravetz, 1993). Post-normal science, through public participation, provides a practice which can accommodate uncertainty and multiple values or stakeholder agendas (Hessels and van Lente, 2008), while considering the particular urgency and constraints associated with environmental and risk policy making. In such situations, an 'extended peer community'

(Funtowicz and Ravetz, 1993) is required to ensure the quality of scientific inputs. Funtowicz and Ravetz (1993) suggest that through the appreciation of different legitimate perspectives and ways of knowing, post-normal science allows scientific research to represent that which should be found in a democratised society, beneficial to both society and the environment.

2.3.3.4 Mode-0, Mode-1, Mode-2 knowledge production

In this model, the relationship between science and society was classified according to three modes, based on current dominant discourses, by Regeer and Bunders (2009). These were mode-0, mode-1 and mode-2 (not to be confused with the Mode 1 and Mode 2 knowledge production of Gibbons *et al.*, 1994, although reminiscent of that framework) where the relationship between science and society goes from very divergent roles (mode-0) to convergent roles (mode-2). Mode-0 (*monodisciplinary*) knowledge is developed autonomously within the field of natural sciences and ‘seeps through’ (Regeer and Bunders, 2009, 43) to society, where it leads to more societal progress. In mode-1, scientific knowledge is used in society (this is *multi-* or *transdisciplinary*). The objective scientific knowledge produced has to be translated and made applicable to societal contexts. Societal and interdisciplinary knowledge is also important in this mode and can lead to new innovations. Knowledge is often policy-relevant and helps resolve societal problems. Finally, in mode-2 (*interdisciplinary and experiential*), there is a requirement for interfaces which contribute to the ‘reflexivity’ of society. Scientific and societal knowledges become difficult to separate and the process contributes to the development of new knowledge (Regeer and Bunders, 2009, 44).

2.3.3.5 Knowledge production through Post-academic science

Ziman (2000) presented the notion of ‘*post-academic science*’, which draws on elements of Mode 2 knowledge production, post-normal science and Academic Capitalism (see below), to describe the ‘radical, irreversible, worldwide transformation in the way science is organised, managed and performed’ (Ziman, 2000, 67), which has occurred within a generation. Hessels and van Lente (2008) suggest that post-academic science, which fundamentally moves away from the traditional, exclusive, autonomous approach to science, can be characterised in five ways. These include collective activity; a need for accountability and efficiency; need for utility of knowledge produced, it is a product of the competition for funds and finally, the ‘industrialisation’ of science has brought academia and industry closer together (reminiscent of the triple helix ideology).

2.3.3.6 Other theories of knowledge production processes

Other analyses of the change in scientific knowledge production which have received less attention, but are worthy of note here include scientific finalisation; strategic research/strategic science, innovation systems and Academic Capitalism. *Finalisation science* (e.g. Böhme *et al.*,

1983) is based on the concept that growing numbers of disciplines are reaching a stage of 'theoretical maturity', (at which point it becomes open to influence from external objectives (Hessels and van Lente, 2008), which means that the relationship between science and society is changing and society takes on a more prominent role in science. *Strategic science* is defined as 'basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of current or future problems' (Irvine and Martin, 1984). The strength lies in the broad approach which allows researchers to follow the most promising lines of research and internalises the pressure for relevance (Hessels and van Lente, 2008). The importance of interaction and feedback mechanisms between all actors (including academics, industry, intermediaries and end-users) is the emphasis of the *innovation systems* approach, which is both a heuristic and prescriptive framework (Hessels and van Lente, 2008). Finally, *Academic Capitalism* (Slaughter and Leslie, 1997) observes the increasing number of 'market-like' activities taking place in universities as a combined result of industry seeking academic assistance, and universities seeking investment. In this way, the two institutions come together.

The above theories describe modes of scientific knowledge production in a variety of contexts and with various controls and outcomes. The next section addresses the role of expertise and context (e.g. river management) in knowledge creation and science studies.

2.3.4 The three waves of science studies

Related to knowledge production, is the issue of science studies and decision-making. Proposed by Collins and Evans (2002), and discussed by Wynne (2003), the *third wave of science studies* (the Study of Expertise and Experience, SEE) is proposed, in order to address the 'Problem of Extension' (i.e. the dissolution of the boundary between experts and the public, which removes the limitations on decision-making rights). The *first wave of science studies* existed in the 1950s and 1960s. During this period, scientific training was sufficient to make one an authority on a specialised subject, and decision-making was uniformly top-down (Collins and Evans, 2002). Beginning in the 1970s and still in play, the *second wave of science studies* (or 'social constructivism') demonstrates the need to draw on 'extra-scientific factors' (Collin and Evans, 2002) in order to make scientific debate complete. Distinguishing between experts and non-experts has become more difficult for sociologists, since they have questioned the difference between scientific knowledge and other forms of knowledge. In the *third wave*, there is a shift from downstream, to upstream thinking, although wave three compliments, rather than replaces wave two, and seeks to find 'a special rationale for science and technology', through the process of '*restructuring knowledge*', to define *why* science should be legitimated and *who* should be

contributing to decision-making. Collins and Evans (2002) claim that in the third wave, those who can be considered experts can only be defined once 'the dust has settled' within a debate. Therefore, the debate process itself develops and identifies the expertise. It is proposed that instead of the traditional model of core science experts (with the most input), wider scientific communities (with limited input), and 'citizenry' (with little input), decision-making should be based on a model in which certain members of the citizenry, with appropriate experiential expertise should be integrated with the core scientists, while the wider scientific community becomes indistinguishable from the general citizenry. In this way, the discussion of science studies and decision-making reflects a number of the progressive models of knowledge production (e.g. Mode 2 and Callon's co-production of knowledge model, see Section 2.3.5). However, the third wave extends its analysis from the role of certain actors, to the importance of the type of science and technology involved. For the case of environmental (and river) science, their classification of reflexive historical science is most appropriate because environmental questions can never be fully answered within controlled laboratory experiments, but require both 'certified and experience-based expertise'. The role of different expertise specifically in the river management context is discussed in Section 2.4.3.

2.3.5 Opening up and democratising science

A common theme in all of the knowledge production frameworks, and most specifically in those which consider the involvement of the public as well as industry and government (e.g. Funtowicz and Ravetz, 1993; Gibbons *et al.*, 1994; Nowotny *et al.*, 2001), is the 'opening up' or democratisation of science. A number of authors have commented on the importance of this, for instance, Beck (1992) suggests that a new logic of risk distribution would democratise science in society as it becomes less opaque and more essential to the political process (although still strongly mediated), and this means that previously existing role differentiation and specialisation becomes less authoritative and more vulnerable (Eden, 1996). As a result, a wider range of knowledges are incorporated and science expands, as other scientists enter the fray (Beck, 1992). The incorporation of wider expertise bases is argued for by a number of authors, in varying contexts, including Fischer (1990); Tombs (1993); Jasanoff (2004a, who sees participation as a democratic right) and Wynne (2007). The first step in democratisation of science, according to Wynne (1992c), is the transformation from a public that is 'impacted', to a public that are 'knowledge generators', making explicit the uncertainties of scientific knowledge, which will encourage 'a wider public debate about the dangers and benefits of pursuing a certain path (Wynne and Mayer, 1993; Eden, 1996).

The fundamental necessity of the development of new methods of public engagement and knowledge use has been highlighted by Jasanoff (2003a) as she expresses the need to consider how 'knowledge-making fits into the wider functioning of society', an ever increasing requirement as the processes and products of science become more embedded in society. In her more democratic view, there are important questions which exist: Who should be involved? and on what terms? (Jasanoff, 2004b). She proposes the adoption of a new social technology: '*Technologies of Humility*' (Jasanoff, 2003a), in which there is a focus on process as well as substance, deliberation as well as analysis. This approach, she suggests, would accommodate the scientific, engineering, ethical and political aspects of research and knowledge production.

Wynne (2007) also suggests that participation should be used to make science more socially relevant, but stresses we should be mindful of the difference between publics 'knowing as well as experts in their technical field', and public knowledge around issues *involving* technical expertise. The latter consideration may often be the most appropriate as it allows us to identify the societal definition of the salient issues and concerns. The societal focus of authors such as Jasanoff and Wynne feed into the practical considerations of knowledge-production offered by Gibbons *et al.* (1994) and Nowotny *et al.* (2001) and many other authors, which have been discussed above.

A classification of the modes of participation in science, made by Callon (1999) describes the progression from linear communication of knowledge (based on the 'knowledge deficit model') to a much higher level of involvement and control. The classifications are in some ways similar to those described above (see Table 2.1), but for the case of river management, Callon's third model (as discussed below) holds particular value.

The Callon (1999) models (Figure 2.1), describe the progression from education of the 'deficient' (Sturgis and Allum, 2002) public, towards the idea that there are certified experts (academics) and non-certified experts (local people affected by an issue) and that each should be involved in the research and decision-making processes. Firstly, the *Public Education Model* (PEM) focuses on a linear communication of knowledge in which (the assumed superior) science is used to restore trust in organisations by educating the (assumed inferior) public. This approach assumes science is correct and sufficient and that the deficiency lies with the public 'lack of understanding'. Secondly, the *Public Debate Model* (PDM) accepts scientific knowledge is 'incomplete' and suggests approval by 'non-certified' as well as 'certified' experts before it can be accepted. However, non-experts are still excluded from the knowledge *generation* process, serving only to 'enrich official expertise' (Callon, 1999). In the final model, *Co-production of Knowledge* (CKM) makes certain 'lay' participants part of a 'concerned group' and a part of the decision-making

process (concerned groups have a ‘specific shared identity’ and appropriate experiential knowledge (Callon, 1999)) – in this case a concern and knowledge about the physical processes of the local area. The model is based on the *production* rather than dissemination of knowledge. In this approach, it is considered that intermediaries are governed by regulatory constraints and internal institutional goals (Clark, 2002). Therefore, by adopting the co-production of knowledge approach, scientists and the public are able to interact directly without the regulatory constraints which may hinder decision-making processes and in pursuit of what may be more common goals (as opposed to those of the intermediaries) (Lane *et al.*, 2011) (although it should be noted that, for river management, ‘intermediaries’ have a significant role to play in translating policy to action (e.g. Bracken and Oughton, 2013)). Under Callon’s CKM, knowledge is co-produced through a process involving those for whom an issue is of particular concern and which recognises ‘more socially distributed, autonomous and diverse forms of collective enterprise’ (Expert Group on Science and Governance, EGSG, 2007, 10).

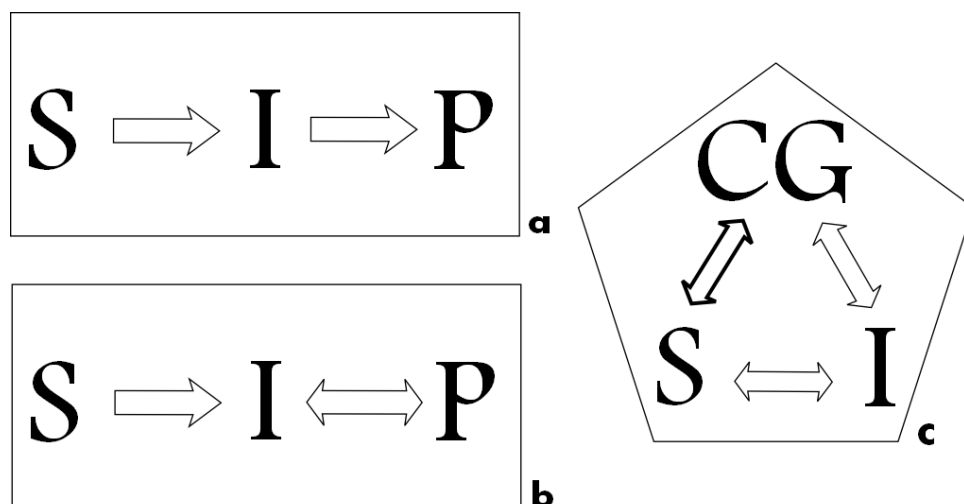


Figure 2.1 Models of participation (after Callon, 1999): a) Public Education Model (PEM); b) Public Debate Model (PDM); c) Co-production of Knowledge Model (CKM). CG = Concerned Group; I = Intermediaries; P = Public; S = Scientists. The double-ended arrows denote two way communication, while single-ended arrows denote a linear flow of information. The heavier arrow in image ‘c’ indicates the dominant relationship

There are increasing calls for river managers to move towards approaches such as the CKM (e.g. Henriksen *et al.*, 2009; Lane *et al.*, 2011). Among other models of knowledge production, Callon’s CKM is, in some ways, comparative with ‘Mode 2’ knowledge production described by Gibbons *et al.* (1994) in that it works around a specific *application*; it is heterogeneous because it involves a

diverse range of organisations; it is reflexive, heterarchical and employs a type of quality control which differs from traditional practice (i.e. social/economic/cultural approval are also important).

Many of the other frameworks of knowledge production, and the changing relationships between science and society are reflective of Callon's CKM, as summarised in Table 2.2.

Framework	Author(s)	Notes on shared attributes
Mode 2, specifically 'middle-strong range contextualisation'	Gibbons <i>et al.</i> , 1994; Nowotny <i>et al.</i> , 2001	Socially robust knowledge is a product of both. Both work around a specific application, are heterogeneous in terms of actors involved, are reflexive, heterarchical (elements of overlap, multiplicity, divergent but co-existent patterns of relation), have novel quality control measures. There are also similarities between Callon's PDM and Gibbons <i>et al.</i> 's Mode 1 in that they are disciplinary, primarily cognitive and deal mainly with science and scientists, but do acknowledge the role of some involvement of 'non-experts'
Triple Helix	Etzkowitz and Leydesdorff, 1998, 2000 and Leydesdorff and Meyer, 2006	Both are application focused and involve a heterogeneous range of actors. Unlike the triple helix, CKM does not specifically categorise academia, industry and government, but focuses on concerned groups, consisting of whoever has a vested interest, experience and/or is motivated to the point of action. The triple helix is more of a 'school of thought', but primarily promoted by Etzkowitz and Leydesdorff, 1998, 2000 and Leydesdorff and Meyer, 2006
Post-normal science	Funtowicz and Ravetz, 1993	Both are characterised by high levels of interaction and cross many disciplinary/organisational boundaries, both use novel quality control criteria and both are reflexive. However, post-normal science is a prescriptive approach limited to policy development
Post-academic science	Ziman, 2000	Post-academic science is very similar to Mode-2 (Gibbons <i>et al.</i> , 1994) and so has the same commonalities with CKM: robust knowledge production, specific application which shapes the process, reflexive, involves a heterogeneous group of actors, is heterarchical and has novel QC measures. However, Ziman sees post-academic science as the science system in a new state, whereas Callon (and Gibbons <i>et al.</i> , for Mode 2) report that CKM (and Mode 2) can operate alongside PDM (or Mode 1)
Finalisation science	Böhme <i>et al.</i> , 1983	Similar to CKM, but with some key differences. Finalisation sciences makes a distinction between different scientific disciplines and finalisation (see Section 2.3.3.6) is usually a result of internal rather than external factors
Innovation systems	Edquist, 1997	Both agree that knowledge exchange should not be linear, and believe research should be based on an application of importance rather than applied after being developed. Both recognise the role of intermediaries
Academic capitalism	Slaughter and Leslie, 1997	Both appreciate the importance of application to a specific context, a range of organisations involved and novel methods of quality control
mode-2	Regeer and Bunders, 2009	Shares many similarities with CKM, the basic principles are the same. Like Callon, Regeer and Bunders acknowledge the importance of mode-1 (or PDM, for Callon) and note that mode-2 (or CKM) can build on and work in conjunction with processes classified as mode-1 (PDM). Both focus on the ability of the mode-2/CKM approach to resolve societal problems, and note that they are reflexive and that the knowledges possessed or created are difficult to delineate according to discipline

Table 2.2 Similarities and Differences between Callon's CKM and a number of alternative knowledge production frameworks

2.3.6 The role of co-produced knowledge in science and technology studies

As outlined above, the processes encompassed in the first two of Callon's models (PEM and PDM) fixate, to varying degrees on demarcation: both 'deny lay people any competence for participating in the production of the only knowledge of any value: that which warrants the term *scientific*' (Callon, 1999, 89). The emphasis in Callon's CKM (and in a number of parallel frameworks) is on an approach which results in the creation of a *new* knowledge (rather than an amalgamation of a number of existing knowledges), which can only be achieved through a deliberative process between a number of actors, including non-certified experts. This *co-production* has been heralded by many in the last decade or so, and warrants some discussion here. For instance, Jasanoff (2004a) noted that explanatory power is gained 'by thinking of natural and social order as being produced together', suggesting that science, policy and government cannot, and should not be discrete disciplines and that a collective understanding of their interactions is required. Co-production is considered to bring to our attention the important, yet overlooked role that 'knowledges, expertise, technical practices and material objects' have in shaping, sustaining, subverting or transforming relations of authority" (2004, 2). This means that power does not reside in particular institutions and in social actors but may be co-produced within particular governance practices, socio-technical interactions, and cognitive assumptions, as suggested by Irwin (2008) and based loosely on ideas presented by Foucault e.g. 1998. Therefore, through co-production, neither science nor society is dominant and each 'underwrites the other's existence' (Irwin 2008, 589).

Callon (1999) notes that public understandings may be 'as highly differentiated as those in scientific communities' (Lane *et al.*, 2011) and that the process of CKM allows both public and scientific understandings to be challenged and reformed into something new through a process of 'dynamic, collective learning'. The key to CKM is the involvement of 'non-experts'. The members of this so-called 'concerned group' must have a specific shared identity which distinguishes them from other human beings (Callon 1999, 90). In other words, there is still a degree of qualification required for the process to work, but this is informal, and case dependent. Furthermore, the CKM acknowledges that in co-production, there is still division of tasks according to different typologies of expertise, but what differentiates co-production from linear information flow, or even limited debate, is that the 'scientists' work in close collaboration with the 'non-experts' and are 'caught in a constant flow of interaction and discussion' (Callon, 1999, 90). The non-experts feed and frame the knowledge produced by the scientists, by the flow of knowledge and questions that they themselves formulate. A number of factors characterise co-production of knowledge and set it apart from less involved practices in which knowledge is transferred. These include: *mutual*

commitment from participants; a common goal, outlined by all participants and; a shared resource pool that is developed as the project progresses to give meaning or create knowledge (Wenger, 1998; Regeer and Bunders, 2009). Ottinger (2013) further extends this idea by suggesting that those who are involved in decision-making do not always have the relevant knowledge at the time that a decision is made, and that technoscientific knowledge will change over time. This has led Ottinger (2013) to suggest that knowledge production and consent of communities to the implementation of decisions should be an ongoing process, in order to truly achieve environmental justice.

Within the context of river and environmental management, there are a number of supporters for the co-production of knowledge approach to inform management decisions and develop knowledge of fluvial, catchment and environmental processes (e.g. Daniels and Walker, 1996; Walker *et al.*, 2006; Petts, 2007; Slobbe *et al.*, 2010; Pahl-Wostl *et al.*, 2011). A number of the strengths highlighted include: a focus on the *process* of learning, rather than the outcome (Petts, 2007); learning through solving collective problems (Petts, 2007); particularly successful in 'context driven' areas where research is conducted with problem solving in mind (Pahl-Wostl *et al.*, 2011); when learning about perspectives, views and knowledge of group members, as well as learning about the subject in question (Petts, 2007). Regeer and Bunders (2009) propose that co-production (or co-creation, as they have termed it) of knowledge helps to prevent the loss of information through translation, that may occur if knowledge is 'transferred' rather than created. They suggest that this is as a result of the intensive interactions involved in co-production, and can lead to the production of 'context-related, socially robust knowledge...which cannot be separated from the context' (Regeer and Bunders, 2009, 44).

2.3.7 The nature of knowledge controversies

Critical to the CKM and to successful *co-production* of knowledge, is the presence of some situation of controversy which drives 'lay experts' (Evans and Collins, 2008) to form a collective with the goal of addressing a particular problem. Referred to as 'hot situations' (Callon, 1998), 'experimental events' (Stengers, 2005) or 'matters of concern' (Latour, 2003), these situations arise when expert knowledge claims, technologies, and the way they are 'hardwired' into governmental practices become the subject of intense public interrogation (Whatmore and Landström, 2011). Disquiet with a scientific issue or knowledge base among a group of people, sufficiently affected by what is at issue, informed by their own direct experience and unconvinced by reassurances from science and policy (Whatmore, 2009), grows to a point of mobilisation among that group, against the 'enemy' (Bucchi and Neresini, 2008, 454). The group is sufficiently mobilised by the situation, to want to participate in collectively mapping it into knowledge, and,

thereby, into its social ordering (Whatmore, 2003; 2009). Through this contestation of the apparent 'unexamined parts of the material fabric of our everyday lives' (Whatmore and Landström, 2011), in other words the unquestioned scientific knowledge and the governance it informs, we, as scientists, politicians, policy-makers, are required 'slow down reasoning', and a different awareness of the problem and situations we face, is aroused (Stengers, 2005). Controversies act as the force fields in which expertise becomes enmeshed with and redistributed through (Whatmore and Landström, 2011) a group of characters which is continually growing and becoming more varied (Callon, 1998, 260).

2.3.7.1 The role of controversies in knowledge production

When dealing with knowledge controversies and knowledge exchange, it has been noted that neither unidirectional nor bilateral modes of communication are sufficient to deal with the complexities of a controversy situation, because within controversies, participants are not required to 'choose one side or the other' and all involved, including scientists, become 'fully-fledged actors' (Limoges, 1993). Therefore, only the types of knowledge production that are described by Mode 2, CKM, etc: only processes which are deliberative and lead to production of *new* forms of knowledge, are appropriate here. Whatmore (2009) describes the anticipation of knowledge controversies as 'one strand' of the much discussed 'Mode 2' knowledge production that attempts to classify the new relationship between science and society (e.g. Gibbons *et al.*, 1994 and Nowotny *et al.*, 2001). The basis of these classifications is the re-distribution of expertise in environmental uncertainties in terms of inter- or transdisciplinary analysis and the 'rekindling' of public confidence in science and policy (Whatmore, 2009). Callon (1998), Latour (2003), and Stengers (2005) all present their versions of controversies as appropriate arenas for challenging traditional 'scientific' approaches to knowledge creation and the production of new knowledge based on new perspectives and refined theories (Callon, 1998). Defined as 'generative political events' (Whatmore, 2009), or 'hybrid forums' (Callon *et al.*, 2009), controversies can incite new ways of practicing relations between science and democracy (Whatmore, 2009) to address issues of mistrust. Limoges (1993) comments that expertise is not a property owned by one person, but a *process*: 'an ongoing learning process which is the result of interactions between participants in a controversy, which in the end defines the status of expert knowledge and sets the limits of its efficacy'. In this way, expert status is itself what is at stake in public forums and must be re-established at each new development in a controversy (Limoges, 1993).

There are a number of well-known cases, around which much of the controversies discussion has been built, including those which have been developed around the food scares during the 1990s within Europe (e.g. BSE and genetic modification), (Stassart and Whatmore, 2003), as well as

techno-science issues (e.g. nuclear power, genetic modification) (Callon, 1999; Bucchi and Neresini, 2008). Callon (1999) presents the example of associations of patients such as a group affected by 'orphan diseases' who, when ignored by institutional medicine, organised themselves as researchers of the diseases and communicated their results with medics as hybrid collectives. In the context of river science, the idea of working with controversies to create new knowledge and new relationships, is relatively unexplored, although there are a few notable case studies. Lane *et al.* (2011) and Whatmore and Landström (2011) document the controversy that existed in Pickering in North Yorkshire which was frequently flooded, but residents could not convince the Environment Agency to provide flood defences. The authors 'harnessed' the knowledge controversy between the lay experts and the certified experts (i.e. the way knowledge was presented in ways that did not allow full scrutiny and which suppressed debate), to create a 'new, collective sense of knowledge' (Lane *et al.*, 2011) which was robust enough to create a new public who were capable of making an intervention into the way flood risk was managed in the town. Some authors have hinted at the importance of public or stakeholder controversy, without fully engaging in the analysis of its roles for river management. For instance, Junker *et al.*, (2007) suggest that only those stakeholders with appropriate levels of urgency should be involved in participatory processes while Newson (2010) observed that optimum results are achieved when individuals with an interest or a cause are facilitated. Additionally, Reed (2008) suggests that some of the most important controls on the effectiveness of participation are the interests and goals of the participants, and how strongly those participants value sustainable development. These observations move discussion some way towards the use of controversies, although they are not fully appreciated within the field of knowledge production for river management.

2.4 Participation in river management

The above sections have focused on knowledge co-production and its benefits for river management. Co-produced knowledge is a product of a high-level participatory approach to research in river management. Participation (as discussed below) can occur at a number of different levels and the level of engagement is linked to the nature of the knowledge produced. As suggested by Callon (1999), Gibbons *et al.*, (1994) and Nowotny *et al.*, (2001) in the above sections, in order to achieve a new, joint understanding of a system or process (i.e. co-produced knowledge), participation must be close, constant, equal in terms of power and representation, and reflexive enough to respond to interim findings. This section discusses the general benefits (or products, which include but are not limited to co-production) of a participatory research

approach, encompassing benefits of many levels of participation, as experienced by a number of river researchers in practical case studies. Co-produced knowledge is considered by some to be the optimum product of river research, while knowledge produced through lower levels of engagement is more achievable, and more common. Therefore, the knowledge products of all levels of participation must be considered.

Despite the strong cases for an approach to environmental decision-making and research that is based around a co-produced knowledge (as discussed above), the process has had limited uptake in river management research. More common in this field is the use of participation at lower levels. Participatory research and its theoretical frameworks were introduced in Chapter One. In this section, the process of participation is discussed in the context of river management for the UK and Europe, and the merits and limitations of the approach, specific to river management, will be presented. To provide a context for this discussion, this section will begin with a review of the different levels of participation and their associated values.

2.4.1 Categorised levels of participation

Participation has evolved over the last five decades, starting with awareness-raising in the 1960s, incorporation of local perspectives in planning in the 1970s, the recognition of local knowledge in the 1980s and the use of participation as ‘the norm’ in the 1990s, through to the disillusionment and beginning of the critique and learning process post-2000 (Reed, 2008). There are three dominant models of approach to public engagement, outlined by Clark (2002). The first and most common approach, the traditional ‘need to know’ approach to stakeholders and the public is, he says, reflective of the classic linear model of behaviour change. This model simplistically assumes that action is determined by understanding of information (Clark, 2002). However, as will be discussed later, this model is not representative of reality and holding stakeholders and the public at a distance can lead to resentment and alienation (Junker *et al.*, 2007). Arnstein (1969) presented a more sophisticated model known as the ‘ladder of participation’, in which a higher level of involvement (and therefore greater influence on the outcome) leads to ‘better’ participation. It describes an increasing level of involvement for each rung of the ladder (see Table 2.3). Further attempts have been made at classifying levels of participation for water resources management (e.g. Biggs, 1989; Pretty *et al.*, 1995; House, 1999; Mostert, 2003; Lawrence, 2006; Henriksen *et al.*, 2009; du Toit and Pollard, 2009), and the overlapping terminology is demonstrated in Table 2.3 (Note that in this table, the term ‘stakeholders’ in the review of Arnstein’s ladder by Henriksen *et al.* (2009) is broader than that used in this study and incorporates any individual involved in, or with a stake in, a participatory process). House (1999) describes three levels of involvement for water management in England and Wales, although

even at the highest level, the focus lies on the development of understanding and awareness of the public, rather than their contribution of knowledge (although this is not omitted entirely).

		Author					Arnstein's definition of the stage (Taken from Henriksen <i>et al.</i> , 2009)
Arnstein (1969)	House (1999)	Mostert (2003)	Henriksen <i>et al.</i> (2009)	du Toit and Pollard (2009)	Wiedemann and Femers (1993)		
Citizens control		Active involvement: Public decision-making			Public participation in final decisions. Assess risks, recommend solutions		Public performs public tasks independently. Stakeholders obtain full managerial power.
Delegated power	Citizen participation	Active involvement: shared/co-decision-making		Collaborate			Public share decision-making powers with government. Stakeholders obtain the majority of decision-making.
Partnership		Active involvement: Discussion	Engagement	Involve			Engagement. Real interaction takes place between the public and government. Enables stakeholders to negotiate in trade-offs with traditional power holders. Some degree of influence. Stakeholders are allowed to advise but power-holders retain the right to decide.
Placation	Public involvement :chance to speak, power is limited		Interaction				
Consultation	Consultation	Consultation	Consultation	Consult	Public define actors, agendas, risks, solutions		Views of the public are sought. Reply forms, opportunity to comment.
Informing		Public information		Inform			The public is provided with or has access to information.
Non-participation					Restricted participation, informing the public		Substitution for real participation. Real objective is not to enable people to participate in planning or conducting programs, but to enable power holders 'to educate' or 'to cure' the participants.

Table 2.3 Terminology applied to levels of participation.

Despite the extensive reflection on 'levels' (or 'rungs') of participation, there are limitations associated with this hierarchical approach, such as the assumption that participation can only improve as the degree of involvement escalates. It is more reflective of practical situations to consider that appropriate level of participation will vary depending on context, such as project objectives, and capacity for stakeholders to influence outcomes (e.g. Rowe and Frewer, 2000; Richards *et al.*, 2004; Tippett *et al.*, 2007; Reed, 2008). Clark (2002 (and Arnstein in later work)) notes that this model maintains a degree of linearity and hierarchy that cannot lead to sustainable river management, because the nature of river studies mean they must be reflexive to result in efficient and appropriate decision-making. Thus, Clark refers the reader to a third model. In this 'wheel' of participation 'all types of participation are options from which an appropriate choice will be made to serve a specific purpose in the management decision-making process' (Treby, 1999) (Figure 2.2). This method of participation is suited to sustainable river management because it allows the level of participation to be chosen based on the requirements of a certain set of aspirations (Clark, 2002). It is adaptive and the level of participation will vary through space and time in order to deliver optimum results.

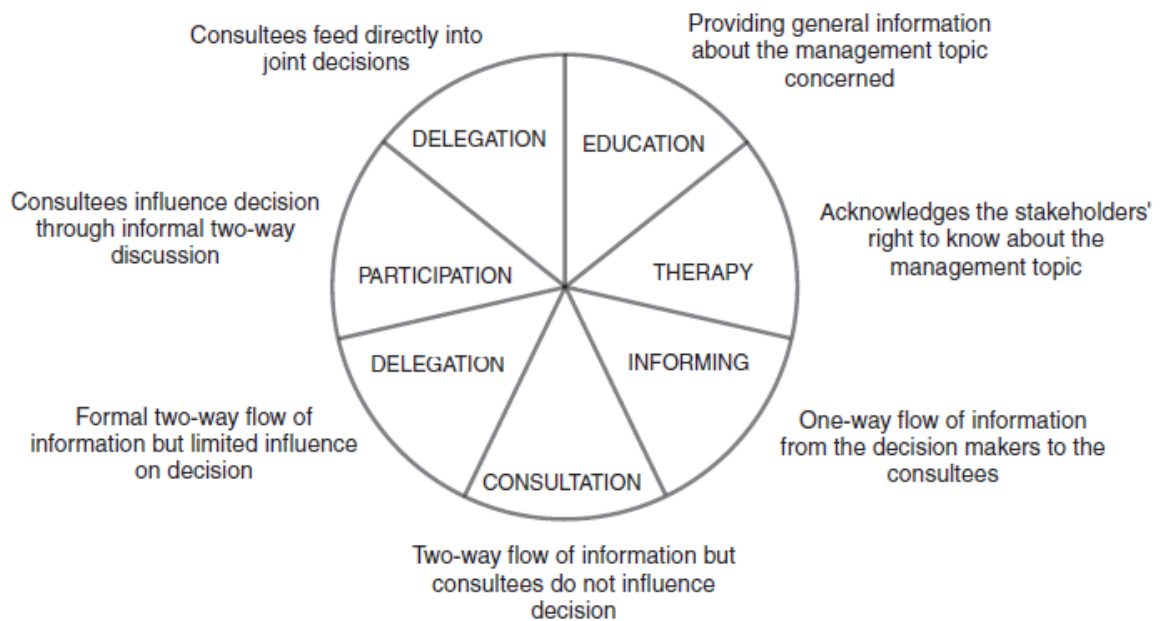


Figure 2.2 Clark's representation of Treby's (1999) 'wheel of participation', in which appropriate approaches are chosen, based on context, and may vary within a project

There have been a number of approaches to classification. For example, Rowe and Frewer (2000) focus on the nature, rather than the degree of participation as the important characteristic and

note that the direction of communication flow between parties should be considered a more valuable characterisation of participation (Reed, 2008). Weideman and Femers (1993) suggest a ladder of participation which highlights the importance of access to information and uses this to classify input level.

A high level of public involvement, such as partnership (Arnstein, 1969), engagement (Henrisken *et al.*, 2009) or involvement (du Toit and Pollard, 2009), can have many benefits and has been widely supported. Clark (2002) notes that higher-level involvement is beneficial because it allows uncertainties to be challenged and provides an arena in which they can be played out. The involvement of the public can help to raise questions and issues that may otherwise have been overlooked. Further, they can assist in the validation of models and proposed solutions by contributing knowledge unique to their experiences (e.g. Welp, 2001; Bowden *et al.*, 2004). This partially addresses the issue discussed by Lane *et al.* (2011), of the significant lack of trust between the public and scientists/institutions because of the current lack of openness and communication in river management processes. Clark (2002) also notes that an iterative, rather than one-off, approach to involvement will benefit river management because it allows an adaptive approach in which targets can be re-set and strategies re-formulated, based on outcomes. This allows a management approach which is responsive to the results it produces and a greater ability to adapt results to achieve greater impact of management efforts. An adaptive approach has previously been supported by a number of authors (e.g. Haney and Power, 1996; Kondolf, 1998; Clark, 2002; McDonald *et al.*, 2004). For example, Tippet *et al.* (2005) suggest that a system of command and control is no longer an acceptable approach to catchment management and that 'double loop' learning (i.e. the capacity to continuously discover, define and correct deep lying errors) allows organisations to adapt to changing circumstances. Public involvement and social learning helps to place the emphasis on developing options as situations change. The benefits of a range of levels of involvement are discussed in Section 2.4.4. Newson (2010) suggests that the future of river science is dependent upon stronger engagement (in whatever form that may take) and that scientists are now tending towards the more involved approaches. Nevertheless, it has been noted that in many cases, despite these calls for increased levels of involvement, common practice is still little more than consultation (e.g. Walker, 2004).

2.4.2 Who are the key actors in a participatory process?

Compounding the issue of the appropriate level of involvement, is the question of *who* should be involved in participatory river management. The US National Research Council (2008) has noted that approaches to public participation in environmental management influence the quality of the outcome and that research on participatory approaches is lagging behind the need (Harris *et al.*,

2012). The report also suggested that the efficacy of process be assessed in terms of the types of individuals that participate. Hansen and Maenpaa (2007) suggest that after deciding what forms of participation to use, *who* to involve is the most important question for those aiming to implement the WFD. It has been widely noted that who is involved in a decision-making or research planning process will shape the focus and outcomes of that process (McDonald *et al.*, 2004).

In the first instance, those who may or may not need to be involved can be divided between stakeholders and members of the public (see Table of Terminology, page xiii for definitions specific to this study). There are examples of research projects which consider stakeholders to be the most important groups to involve (e.g. Reed, 2008), and cases in which it is believed that the public are more appropriate participants e.g. (Lane *et al.*, 2011). In many cases, however, consensus simply cannot (or has not) been reached, over who should be involved (Junker *et al.*, 2007). In his review of stakeholder participation for environmental management, Reed (2008) focuses his analysis around the involvement of stakeholders because, he suggests, in conservation, the dominant approach is to 'engage those who have a stake in the scope of their initiative', rather than attempting to meaningfully engage with the wider public. The nature of the objectives for the project may help to determine who should be involved. If a process that includes participation is required, but with minimum conflict, Junker *et al.*, (2007) suggest that using stakeholders is preferable to the wider public. However, if the goals are to develop ownership, trust and improved decision-making, then the wider public should be involved. Junker *et al.* (2007) suggest that there are three things to consider when deciding who should be involved in a river restoration project. First, are the river corridors a meaningful part of the residents' everyday life? Second, would stakeholders adequately represent the aims, preferences and interests of residents? Finally, do the aims of the wider public clash with those of the project team? In order to make a successful decision on who to involve, project managers need to understand the social relevance and context of a river to a community. Furthermore, in much STS literature, the strengthening of the relationship between the 'scientist' and the 'public' in research has been emphasised (e.g. Callon, 1999). However, in the field of river management, the intermediaries cannot be omitted entirely, indeed they play a crucial role in translating policy into practice, appointing appropriate participants and taking responsibility for works (e.g. Bracken and Oughton, 2013).

Catchment management groups can be assigned to one of three categories, described by Cook *et al.* (2011): *regulatory catchment groups* (e.g. the Environment Agency, who have focused on

stakeholder consultation), *statutory groups* (e.g. Water Framework River Basin Liaison Panels: thematic in nature and still with statutory powers, like the Environment Agency), and *voluntary catchment groups* (formed in a grass roots fashion, to discuss and deal with a perceived problem). They are suited to poly-centric governance because of their flexibility of working. Many of the UK's Rivers Trusts started as voluntary catchment groups. Each of these groups play a role in the catchment management process and, as described above, have an impact on those chosen for participatory practices, often based on the remit of the management group.

The role of different members of the public is discussed by Harris *et al.* (2012), with a focus on the contributions made by self-selected versus actively engaged members of the community. It is suggested that the inclusion of diverse community interests is necessary to record the concerns and perspectives of the broader community (Fiorino, 1990; Renn *et al.*, 1995; Bauer and Thomas, 2006). However, *who* is actually involved in traditional public meetings influences the outcomes and the perspectives represented. When meetings and dialogue are open to anyone, attendance has been observed to be dominated by white, Caucasian, affluent, educated, males, with a high status in the community and often with different values to those of the community in general (Hansen and Reinau, 2006; Hansen and Maenpaa, 2007; Harris *et al.*, 2012, examples of this include McComas, 2001; Anthony *et al.*, 2004; Marshall and Jones, 2005; Halvorsen, 2006). This results in a skewed representation of community values and needs. Conversely, the discussion that takes place between diverse participants (in a more deliberative process) can facilitate free, open and meaningful dialogue about what is of importance to a community (Harris *et al.*, 2012, examples include Tuler and Webler, 1999; Webler and Tuler, 2000; Becker *et al.*, 2003). Careful and strategic selection of individuals for the deliberation process can help to form a group of people who have in-depth experiential knowledge and/or are able to communicate effectively with and about community aspects or values which may otherwise be neglected (Harris *et al.*, 2012). It could be argued, however, that other community members are speaking through their absence.

Creighton (1983) suggests a number of criteria are important when considering which members of the public should be involved, based on how each individual would be affected by the decisions made. These include *proximity* to plan implementations; *economic* impact of decisions; impacts on a person's *use* of the system; *social* or *cultural* implications of changes, and the impact on the *values* of the community in relation to the river in question. An alternative approach to deciding on the level of involvement appropriate for an individual is Jackson's (2001) classification according to the level of extant knowledge the participant possesses. This approach allows a

reflexive system of involvement which should suit the needs of each individual, although such a detailed analysis would be overly time consuming at anything other than a very local scale. Naturally, the issue of appropriate participants escalates with catchment or project scale, according to Hansen and Maenpaa (2007) and is further complicated when water management projects cross environmental borders or boundaries which differ to political ones (as is common within the scope of the WFD).

2.4.2.1 The role of the voluntary sector

In recent years prominence of the voluntary sector as players in the river management process has grown. Cook *et al.*, (2011) suggest that a decentralised governance model of management has its natural home in the voluntary sector, due to the sector's flexibility and its ability to meet local needs. The nature of the development of voluntary management groups (through response to a perceived problem (Cook *et al.*, 2011)) allows such groups to identify and engage with a diverse range of people who are likely to have particular interests in river management. In contrast, traditional regulatory bodies are often technocratic (Newson, 1992) and statutory groups are often development-led (Cook *et al.*, 2011).

Organisations such as the Association of Rivers Trusts, many of which begin as a community-led group of concerned individuals focused on a specific problem, now play an important role in delivering catchment management objectives. The Rivers Trusts fill a unique niche between government organisations and the public (Newson, 2010), often mediating between the two when organisations struggle with engagement and legislation (Newson, 2010). These organisations, due to their provenance as well as their current approach to open and involved river management often earn a level of trust from communities which does not exist between the statutory or regulatory bodies, and the communities. Cook *et al.* (2011) refer to this as the 'moral authority' and as a result of this relationship, voluntary sectors often achieve a level of engagement, understanding and learning that is alien to regulators.

There are limitations however, for example, many of the voluntary bodies in river management in the UK began with a community concern around fisheries. Cook *et al.* (2011) suggest that management by the voluntary sector needs to make a shift towards more broad reaching groups, such as those that deal with flooding or water quality (although the author believes that many of the Rivers Trusts would argue that they have already evolved to this point and most of them make invaluable contributions to delivering many of the current WFD objectives). Furthermore, there are currently issues around accountability and informality for the voluntary sector and Cook *et al.*,

(2011) suggest their role needs to be formalised, and that a new vision is required in order to 'accommodate the new localism represented by many voluntary groups operating on the ground'.

2.4.3 Defining 'expertise' in participatory processes

The role of individuals or groups within a participatory process may be shaped by the perspective that those in power have of expertise. Bracken and Oughton (2013) describe two distinct perspectives of expertise which may focus on i) expertise as epistemology: a measure by which to classify people, based on the type of knowledge they possess (e.g. Collins and Evans, 2002; Turner, 2006; Collins and Weinel, 2011), or ii) expertise as a social process, in which it is conferred upon individuals (e.g. Jasanoff, 2003b; Wynne, 2003). Practitioners with the latter perspective may be more open to reflexive participatory processes (through which expertise may be gained or shared), while those adopting the former perspective may have pre-conceived judgements of which types of expertise (and therefore which groups of people) are appropriate for a certain participatory process. This is not necessarily a negative approach, indeed, it may be beneficial in designing a participatory process and determining who to involve. However, care must be taken not to exclude certain individuals based on assumptions about the value of the knowledge they possess. Considering expertise to be a social process may also have power implications as certain individuals influence who and what knowledge is relevant in decision-making, and who deserves to possess that knowledge (Bracken and Oughton, 2013).

Within the context of knowledge controversies, conflicts of expertise in various forms can be used to 'enmesh and redistribute' expertise in order to map the issue into knowledge and into social ordering (Whatmore, 2009), at which point, the issue can be addressed with a new understanding, which is based on input from a 'varied cast of characters' (Callon, 1998, 260). The issues addressed in river management span the realms of both the social and the technical, one cannot be addressed in isolation and therefore the very nature of the application requires expertise to be transgressive and diverse (Nowotny *et al.*, 2003). Participatory approaches aim to achieve this through the enmeshing and redistribution that accompanies a knowledge controversy (or a less controversial but equally important research question) – thus taking the expertise possessed by the diverse group of participants (the certified and non-certified experts), and creating a new form of expertise.

2.4.4 Benefits of participation and use of public knowledge for water management

Public participation is supported in river management because it has been determined that the people who use the river system have a right to be aware of changes that are being made, and have the potential to contribute valuable, unique, area specific knowledge (e.g. Burton, 1995;

Callon, 1999; House, 1999; Blackstock *et al.*, 2007; du Toit and Pollard, 2008; Henriksen *et al.*, 2009). Clark (2002) describes four aspects of river management which make it suitable for success with participatory approaches: sustainable management, coping with uncertainty, adaptive management and decision support. It is suggested that if these four aspects of emerging river management processes are inter-linked, they will complement a participatory approach which can lead to efficient management.

The benefits of participation, in its many forms, have been documented extensively and are too numerous to be discussed fully here. They are summarised in a table in Appendix A and a discussion of the most pertinent benefits, for catchment planning, is provided below.

The fundamental merit of public participation in river management is the nature of the knowledge possessed by members of the community (and sometimes stakeholders). This knowledge is often local and historical (Walker, 2004), and inaccessible via systematic periods of monitoring (such as regulatory bodies or scientific researchers would use). Furthermore, all relevant information cannot be assigned to observable data. The issues which exist for individuals, communities and organisations influence how river management is delivered and perceived and should be used to inform management and communication approaches. Participatory approaches can be used to enhance the understanding of various parties concerning the issues and needs for others (e.g. issues of flood management, as demonstrated through a study on Flood Management in Borderlands, Tweed Forum, 2012). The diversity of knowledge held by a group which includes both scientific experts and local experts allows each member of the group to identify their own position and that of the other group members (van den Hove, 2000; Pahl-Wostl, 2002; Carr *et al.*, 2012) and thus develop 'shared priorities' (Petts, 2007).

Management which involves participation can be reflexive. Clark (2002) notes that an iterative, rather than one-off, approach to involvement will benefit river management because it allows an adaptive approach in which targets can be re-set and strategies re-formulated, based on outcomes. This allows a management approach which is responsive to the results it produces and a greater ability to adapt results to achieve greater impact of management efforts. An adaptive approach has been supported by a number of authors (e.g. Haney and Power, 1996; Kondolf, 1998; Clark, 2002; McDonald *et al.*, 2004). For example, Tippett *et al.* (2005) suggest that a system of command and control is no longer an acceptable approach to catchment management and that 'double loop' learning (i.e. the capacity to continuously discover, define and correct deep lying errors) allows organisations to adapt to changing circumstances. Public involvement and social learning helps to place the emphasis on developing options as situations change, thus

making the final results and decisions more robust, and often more widely accepted within the community, as well as increasing the level of ownership and responsibility accepted by the participants.

Public participation can improve the efficiency and the focus of river management practices. It allows practitioners to identify the issues which are of importance to the community, and to focus research approaches using this insight. The decisions made, as a result, are often relative to the community that defines, and re-defines the river/reach in question (Eden *et al.*, 2000; McDonald *et al.*, 2004). A participatory approach can help to provide a variety of ideas and perspectives in project design, particularly when the participation starts *early* in the project (Reed, 2008). In this way, the work or research carried out can be tailored to the needs of the community, and to the context of that particular reach or environment. Further to benefiting the community and the environment, Walker *et al.* (2004), speaking from a public agency perspective, note that this can help to reduce conflict between regulatory agencies and community groups, as well as within community groups. The development of a community understanding of the processes and pressures on statutory and regulatory organisations in river management has also been cited (Walker, 2004). This enhanced understanding may harbour a number of benefits including increased acceptance of management approaches, and improved working relationships between communities and managers.

Further to the benefits that participation can provide to the immediate project, it can help to forge relationships which will facilitate in future projects by creating a platform of trust and communication that can be re-visited (Walker *et al.*, 2004).

2.4.4.1 Social learning and participation

One of the most significant benefits of participation, and one which requires special attention here, given the research approach being devised in this thesis, is *social learning*. The term 'social learning' is defined differently in the context of different projects and can encompass a number of phenomena and concepts (Maarleveld and Dangbégnon, 1999; Mostert *et al.*, 2007; Pahl-Wostl *et al.*, 2007). For example, it has been defined as 'the way in which people learn to get insight into, predict and control the manner in which their actions affect natural and human life' (e.g. Rist *et al.*, 2003, 263; Newson and Chalk, 2004). Tippett *et al.* (2005) suggest that organisational learning, which enhances the ability of a group to change its underlying dynamics and assumptions can be considered as social learning, while Cook *et al.* (2011) define the process as a form of 'knowledge transfer by participation and from engagement with others, but in an informal setting, such as volunteer engagement'. The varying definitions all allude to some kind

of learning among a group, which is a result of the group sharing their knowledges and experiences, and the learning that occurs belongs to the group and not the individual. The key here is that such knowledge cannot be developed independently, or in the absence of a diversity of participants, it informs both the certified experts and non-certified experts and the result of it may extend beyond the original research question to affect human behaviour/response (Maarleveld and Dangbégnon, 1999). As Tippett *et al.* (2005) suggest, whilst 'our experience of knowing is individual, knowledge is not'.

Social learning is a process that can occur within a natural and/or social context (e.g. Craps, 2003; Ridder *et al.*, 2005; Pahl-Wostl *et al.*, 2007) and is essential for sustainable environmental management (e.g. Robinson, 2003) because it promotes desirable behaviour change, involves new collaborations (Pahl-Wostl *et al.*, 2007; Slobbe *et al.*, 2010) and subsequently, collaborative learning (Cook *et al.*, 2011) and facilitates collective decision-making (Pahl-Wostl *et al.*, 2007; Muro and Jeffrey, 2008). The challenges posed by climate change, the WFD and the particular complexity inherent in water management (Tippett *et al.*, 2005) make social learning fundamental to the resource management process. However, social learning can be limited if stakeholders and participants are not given sufficient opportunity to be involved in the decision-making process (e.g. by the water industry and water authorities: (Cook *et al.*, 2011). One of the key characteristics of social learning is the 'double-loop learning' concept, developed by Argyris and Schon (1978). Double-loop learning allows a group to repeatedly identify and address errors, which facilitates an organisation in adapting to changing environments, learn from the lessons of the adaptation and amend underlying approaches accordingly (Tippett *et al.*, 2005). Pahl-Wostl *et al.* (2007) note that the fundamental value of double-loop learning is in the radical change to underlying values and beliefs, which then encourage a new way of working. In a similar way, the process of social learning is a cyclical one, in which the social and environmental context impact upon the way in which groups work together and learn together to make decisions and to change their approach (which act as the outcomes). In response to the outcomes, the original context changes, and the group must then deal with the new issues associated with that context and the cycle begins again (e.g. Tippett *et al.*, 2005; Pahl-Wostl *et al.*, 2007).

Participation can also be seen as an important precursor to social learning (as well as a worthwhile outcome) because it is through the interaction of different parties in a participatory process, the understanding of each others' viewpoints and the development of ideas around how they can impact the environment, that encourages and results in social learning (e.g. Tippett *et al.*, 2005). The factors required for a successful social learning approach are similar to those of a

participatory process and include careful planning and facilitation, an environment of trust and openness, early involvement of all parties and enough time to allow the project to progress properly, prior agreement of approach, goals and responsibilities (Tippett *et al.*, 2005). Like any process, there are limitations and inhibiting factors to social learning. These may include time constraints, incorrect or insufficient representation of (or by) stakeholders, lack of interest and mismatched expectations.

2.4.5 Participatory approaches utilising traditional river research methods

Many tools exist to aid participatory research and they can be scientific as well as social, thus opening up river research to interdisciplinary approaches. There has been development in recent years of a number of scientific tools that can specifically facilitate public participation in river and environmental management. These approaches are designed to achieve the most efficient or effective modes of knowledge exchange and development. Harris *et al.* (2012) discuss the role of different types of group meeting and how variations in the set-up of these meetings can impact on the outcomes. Traditionally, the most common form of participation for river management has been the *public meeting*, which anyone may attend, although this approach has received some criticism (e.g. Rowe and Frewer, 2005; Halvorsen, 2006; Reed, 2008) concerning the quality of citizen and input and the representation of all stakeholder concerns (Harris *et al.*, 2012). Harris *et al.* (2012) discuss an improvement to the traditional public meeting, in the form of an '*analytic-deliberative process*'. The strength of this approach lies in the small group processes which encourage the sharing of knowledge between participants and 'capitalises' on the culmination of ideas and consideration of the diversity of the viewpoints presented by the participants (Gigone and Hastie, 1993).

The importance of visual information has been highlighted (Larson and Esdall, 2010; Newson, 2010) and one of the dominant approaches to this is the use of *Geographic Information Systems* (GIS), which is to document and communicate various forms of knowledge between managers, scientists and participants (e.g. Gonzalez, 2002; Bunch and Dudycha, 2004; Tippett *et al.*, 2005; Brown *et al.*, 2012; Giordano and Liersch, 2012; see also Chambers, 2006 for a discussion of the power roles created when tools such as GIS are used). Peng (2001), developed a classification of web-based and GIS activities which can be used in knowledge exchange. The levels progress from general information provided by web browsing, to scenario building using analysis tools. This demonstrates that, as in the general approach to participation, the tools used can be adapted to assist in different levels of involvement. Hansen and Maenpaa (2007) champion the many possibilities offered by the internet, such as basic information provision, GIS tools, 3D visualisation of catchments, and speedy, direct and efficient feedback systems for participants to communicate

with managers. They do note, however, that managers must take care not to exclude certain demographics (such as the elderly or rurally isolated) by adopting only web-based approaches to participation. If the web is the main form of communication process in a participatory approach, then the impacts that this will have on the opinions presented and the knowledge developed, must be considered in the analysis stages.

2.4.5.1 Numerical modelling in participatory river management

Perhaps one of the most involved, and most relevant tools for participation in river management is the inclusion of participants in what was traditionally an exclusively scientific approach: *numerical modelling* (in which data concerning a catchment are used, in combination with a number of known physical rules, to predict how a river or catchment may respond to certain conditions (see Chapter Six for full details)). The involvement of participants in the modelling process has multi-directional benefits. First, the quality of the model outputs and the decisions made can be more robust and more focused on the specific issue, when informed by local knowledge and concerns. Second, the process of modelling with participants can result in increased trust in the outputs, stronger group relationships, an understanding of the traditional approaches adopted by river managers and the efficient resolution of a problem. A specific strength of higher level participation for river (and wider environmental) management is that of model validation, and validation of process assumptions through lay knowledge (e.g. Funtowicz and Ravetz, 1991; Renn *et al.*, 1995; Welp, 2001; Bowden *et al.* 2004; Petts, 2007; Henriksen *et al.*, 2009). I return to Lane *et al.* (2011) for a demonstration of this. They documented multiple benefits arising from a very high-level participation project with a community group which had experienced repeated fluvial flooding in North Yorkshire. In this approach, the knowledge of the residents and farmers concerning the nature of flooding (e.g. flow routing and small but significant obstacles to flow which would have otherwise been overlooked) was incorporated into a model of flood risk for the area of Pickering and the model was modified and built to incorporate the observations provided. The outcomes of the project included the co-production of knowledge between the certified and non-certified experts and a public intervention in flood risk management, which was previously unattainable between the community members and the statutory authority (the Environment Agency). The process developed confidence within the community members to work for, and achieve the flood risk measures required by the village. Lane *et al.* (2011) consider one of the main achievements of the project was in 'making their model perform', although not 'scientifically' validated (i.e. compared to extant data) at the point of discussion, the model is considered to have been validated by achieving the trust and acceptance of the community members, through an interactive development of the model itself

(the usefulness of an ‘un-validated’ model as a tool for discussion and enhanced understanding of a process is also highlighted by Voinov and Bousquett, 2010). Prell *et al.* (2007) used local expert knowledge as a form of model validation by allowing participants to comment on the feasibility of model outputs, and the subsequent refinement and development of their model. Stringer and Reed (2007) suggest that this process can assist in rapid and constructive model validation. The view that model validation and process assumption validations can be enhanced using participation and local knowledge is one that has been echoed by a number of authors, including Henriksen *et al.* (2009); Voinov and Bousquett (2010); Krueger *et al.* (2012); Oliver *et al.* (2012). Oliver *et al.* (2012) suggest that the benefits of model validation extend beyond robust model outputs, but in fact can assist in developing an integrative and collaborative approach to decision support systems for identifying farming practices that are likely to impact environmental quality, as well as increase uptake of the decision support systems by farmers (see also Landry *et al.*, 1996 for the importance of legitimacy of model for uptake by a community). Further to the community-based and environmental benefits of Lane *et al.*'s (2011) work in North Yorkshire, the relationship between the community and the scientists/professional stakeholders was improved, in what Jasanoff (2003a) calls the ‘hybridisation of science and politics’, and made their approach particularly radical. The use of ‘traditional’ river research methods in the ways described above demonstrates that there is no contradiction between scientific methods and participatory research. Rather, the key to using the two successfully lies in the way partners work together and the level of participation achieved.

2.5 Critical review of participation in river management

Despite abundant claims of the benefits of a participatory approach, there are inevitably drawbacks to the process and aspects which require caution. The following sections will outline some of the limitations and present a critical review of participation as a river management tool.

2.5.1 Limitations

As fruitful as participation is claimed to be, debate remains concerning its capacity (Lubell, 2004; Muro and Jeffrey, 2008; Carr *et al.*, 2012). There are a number of limitations with participatory approaches to river management and most are related to power imbalances, and what may result if those applying the suggested process are not fully committed, or are disillusioned about the possible outcomes. The limitations are summarised in Appendix B and some of the most relevant issues are discussed below.

Conducting participation which is incomplete and not thorough can potentially have greater risk than not using participation at all. Reed (2008) notes the detrimental impact that can be experienced when participatory processes do not deliver on the claims that are made. This is potentially one of the most important implications of superficial participatory management because it can lead to lack of trust, loss of enthusiasm and inadequate outputs for that and future projects. If outputs are delivered, it is very difficult to maintain these and sustain the changes that are made (Clark, 2002). It is imperative that this scenario is considered at the beginning of the process in order to avoid leaving participants with a responsibility they do not wish (or did not agree) to accept. The interpretation that is placed on 'participation' can be strongly linked to its success. As noted by Tippett *et al.* (2005), some authorities may prefer to fulfil the minimum requirements to comply with the legal regulations while others may see participation as an opportunity to change their practice of river management. This interpretation will influence the experience the participants have and the success of the project.

One of the most significant ongoing drawbacks for participatory processes is the unwillingness of some academics and managers to accept public knowledge as 'valid'. As described by Eden and Tunstall, 2006, many aspects of policy retain the 'deficit model' (Sturgis and Allum, 2004) and communication between experts and public is 'downstream' (Hilgartner, 1990) because policy primarily relies on science to identify environmental risks, thus raising the profile of science (Beck, 1992; Eden, 1996) (at least *within* the realms of policy and science). The resistance to accept public knowledge can cause negative impacts in a variety of ways. Public authorities may be reluctant to devote resources or funds and time to participatory projects, when they believe that decisions concerning complicated matters 'should be left in the hands of the experts' (Hansen and Maenpaa, 2007). Eden (1996) suggests that public views and opinions are not considered 'scientifically expert' and because of the scientific construction of environmental issues and the dominance of discussions by 'scientific experts', public participation in policy making is hindered. Eden (1996) suggests that the solution to this is not to try to educate the public, or transform them into 'scientists', but for policy makers to develop decision-making methods which allow consideration of the other (non-scientific) ways in which people relate to their environment. The lack of confidence in public knowledge and competence can lead to their exclusion from decision-making processes, particularly when conflict avoidance is a priority. In these cases, stakeholders, rather than members of the public, are often appointed to fulfil participation requirements (Junker *et al.*, 2007). This can lead to a number of weaknesses in the participatory process.

The complexity of producing knowledge which is both 'scientifically robust' and socially relevant is further compounded by the ongoing requirement of academic literature for science based results and procedures in river management. Eden and Tunstall (2006) suggest that this applies in both river restoration studies and many 'non-restorationist environmental initiatives' It is also noted (e.g. Bracken and Oughton, 2006) that securing funding can be problematic when research cannot be traditionally categorised according to institutional frameworks. When planning research objectives, this will influence the approach taken by many academics, as professional success is quantified through funding acquisition and publishable outcomes. The issue of funding and resource provision is further complicated by conflicting ideas and agendas over appropriate allocations of funding (Cook *et al.*, 2011).

The importance of scientific knowledge is not forgotten in participatory process. Indeed, many participants would require a sound scientific basis for a decision-making process. Chase *et al.* (2004, 635) developed a number of criteria for evaluation of participatory processes, based on criteria cited by the stakeholders and participants themselves. In this study it was identified that alongside having an influence on decisions, treating citizens equally, and promoting communication and learning, one of the most important criteria was the use of the best available scientific information. Furthermore, in most cases statutory authorities remain responsible for project outcomes and implications. Therefore, it would be inappropriate for them not to have some sway over the way decisions are made (Walker, 2004) (and what knowledge is used to inform them).

Countering the numerous claims that participation is beneficial, if not essential, for successful river management, there are examples of cases which question whether the process is always worthwhile. While Carr *et al.* (2012) note that there are no studies documenting the *negative* impacts of participation on resource management, it has been suggested that there is limited evidence to support assumptions that participation *enhances* resource management (Carr *et al.*, 2012: examples include Coglianesi, 1997; Koontz and Thomas, 2006; Reed, 2008). Reed (2008) suggests that in light of the proclaimed benefits of the participatory process, 'disillusionment has grown amongst practitioners and stakeholders' when claims are not realised and the results not delivered (see also Rhoades, 1998, p4). While Rhoades (1998) appreciates the value of participation in watershed management, he advises that a number of conceptual and operational 'landmines' must be addressed to avoid comments from critics which may obstruct the many benefits that are potentially available. These include: the confusion between physical and human organisational scales; the use of participatory approaches for the wrong reasons; the

disproportionate credit assigned to the physical and social aspects; unrealistic expectations (see also Hansen and Maenpaa, 2007), loss of participation through unresolved conflict; duplicating management structures and misrepresenting the role of certain players, and complexity and competition between participants.

2.6 The way forward for knowledge production and public participation in river management

Despite the plethora of literature surrounding both knowledge, and participation in river management, there are questions which remain. To the author, the most pertinent of these appear to fall into three categories. First, the continuation of knowledge development which seeks to first create knowledge, and second apply that knowledge to an issue that currently exists (rather than develop knowledge around an application); second, the absence of critical assessments of 'shallow' participation and the lack of reflection on the learning achieved by the traditionally labelled 'experts', managers, or organisations, and finally, the problem of achieving high levels of engagement, such as co-production of knowledge, at a range of scales, and in the appropriate locations. Each will be considered briefly in turn.

Many of the knowledge production theories which claim that traditional approaches to scientific knowledge production was based around research that was conducted without a specific application in mind (e.g. Gibbons *et al.*, 1994; Callon, 1999; Nowotny *et al.*, 2001) prescribe knowledge creation which is guided by an application or specific context. Many participatory projects have been documented in river management, but few have grown out of a community need or a controversy (see Callon, 1998; Latour, 2003, or Stengers, 2005) and participants are often selected after the issue itself has been identified.

Reflection on participatory processes is important in order to develop and inform both the current process and future knowledge integration attempts (building on the reflexive nature of a project that is prescribed in many of the knowledge production theories). Petts (2007) notes that limited academic literature exists on the learning that comes out of public engagement, and particularly, the learning of the 'experts', 'scientists' or organisations.

The issue of scale must also be considered. Number of stakeholders or participants and planning challenges is understood to increase with scale (Adams and Perrow, 1999; Hughes *et al.*, 2001; Adams *et al.*, 2004) and while true participation usually relates to small stretches of river (House,

1999), environmental policy operates at much greater scales (Eden, 1996) and it is large reach and catchment scales that are most commonly in need of problem solving through deliberative and interactive processes. Contradictory to these requirements, involvement of local expertise at large scales is complicated by the simple fact that those with experiential knowledge are close to a site or system (Newson, 2010) and experiential knowledge is inherently local. The location of the majority of previous scientific studies also limits the creation of socially and environmentally relevant knowledge. For example, the preference within intellectual, research-based investigations to study 'pristine, upland' rivers in the UK over degraded systems at the national scale (which is the issue more in need of pragmatism), is highlighted by Newson and Large (2006, see also Graf, 2001, 17).

Although there are numerous studies involving participation of some sort in river management, as highlighted in Section 2.4, the higher levels of participation, i.e. knowledge co-production, are severely limited (despite Collins and Evans, 2002, suggesting that the type of science involved in river management decision-making - reflexive historical science - is what benefits most from co-production of knowledge). Combined with the issues of participation and knowledge creation at varying locations or scales, and the apparent necessity for research to be based around a specific application in order to make the knowledge produced relevant and robust, a number of research questions have been formulated for this thesis:

1. What approaches to participation in river management currently exist, and are the different approaches identified characteristic of certain contexts?
2. Can innovative approaches to river management practices be developed to deliver more socially relevant outcomes which assist both certified and non-certified experts to learn about the environment in question and about the process?
 - a. Which methodologies or tools can be used to investigate a research problem and bring together traditional scientific and specifically local experiential knowledge?
 - b. Which actors can (or should) help to formulate the new knowledge, and are there any criteria for involvement?
3. What role can experiential knowledge play in problem solving and how can it be incorporated into the research process?
 - a. Can practical examples in the field of river management be applied to any of the knowledge frameworks prescribed or described by STS literature?
 - b. Why has there been limited use of controversies in creating improved knowledge in river management scenarios?

4. How important is scale? Can the principles outlined in the suggestions for the co-production of knowledge theories be scaled up? Are approaches transferable to new sites and new problems?

Therefore, an approach for this study has been adopted which is participatory, interdisciplinary, and aims to create an environment suitable for the co-production of knowledge within a concerned group. The participatory nature of the research is designed to allow a new knowledge to be produced between that concerned group by sharing information in a range of formats. The specific approaches taken are discussed in the next chapter and the following chapters document the results of the approach and the implications for future river research and management.

Chapter Three

Methodology

3.1 Introduction

The research questions established in the previous chapter are addressed through a mixed and interdisciplinary methodology. This includes a study of current Organisational approaches to participation in river management, and the investigation of a local (reach scale) catchment issue for a concerned group of citizens. Epistemologically, the nature of the Ebchester Study project requires focus upon two very different, even contrasting, types of environmental knowledge. There is scientific knowledge – attained from physical and numerical data - of the physical characteristics of the river, which may be on a reach, sub-catchment or catchment scale. The other type, experiential (or ‘lay’) knowledge, is possessed by those who live with the river on a daily basis and is more likely to be detailed around a small area (e.g. in the reach in which they prefer to fish, or the stretch that runs through their land). The aim here is to facilitate communication of these different types of knowledge in order to lead to the *co-production* of a new knowledge. The process by which this is achieved is outlined in this chapter.

The present chapter first introduces these two stages of data collection. The stages, steps and methods followed in the data collection process are summarised in Table 3.1. The thesis structure is explained briefly to show how the contrasting aspects of social and physical data collection were incorporated into one thesis, and the research steps are then discussed in turn. First the interview method for the Organisational Review is described and justified, followed by a step-by-step account of the interdisciplinary, participatory study. This includes identification of catchment issues, establishment of a competence group and of their research objectives, a brief note on physical field data collection and model development, and the process by which the various forms of knowledge were integrated. The limitations to the chosen approaches are

outlined and an ethical review discusses how considerations of ethics in participatory work differ from those adopted in more traditional research approaches.

3.2 Research stages

The research and data collection components of this study can be divided into two stages: the Organisational Review, and the Ebchester Study. Each of these stages produced their own free-standing results, but also produced results that provided context for the other stage, and together they allowed a broader discussion of the role of participation in river management and research to be developed. The two stages are outlined below.

3.2.1 Stage 1: Review of organisational practice

To provide context to the overall study from a broader scale, the research in Stage One focused on a sample of formal river management organisations (OROs: Organisations specifically involved with the Organisational Review), where Semi-structured interviews were carried out to determine how participation is currently used and viewed in the river management sector in the UK and Western Europe. The aim for this stage was to identify and analyse the way in which river management organisations view and conduct participatory research as part of their wider management remit. This stage of the project provided its own results, as well as establishing a context for the Ebchester Study by identifying common practices and issues, as well as some more unique approaches. These findings were carried into the conceptualisation and planning of the small scale, more reflexive Ebchester Study.

3.2.2 Stage 2: Interdisciplinary participatory research

The unorthodox field of research in this thesis requires an interdisciplinary framework which includes both traditionally social and scientific approaches; this interdisciplinary approach is necessary in order to draw together the social and physical aspects of river management as one unified process. It also involves a participatory research approach (as defined and discussed in Section 1.5). It explores the role of the 'co-production of knowledge' approach within this framework to determine whether it is as valuable in practice as it is in theory. Figure 1.2 demonstrated how the individual components of local, experiential knowledge, and traditional scientific knowledge contributed to the research process and were brought together to answer the research objectives set by the group (Section 5.5). Participatory methods (including drop-in sessions, participatory mapping, focus groups and site visits) were used to engage the population of the Derwent catchment, determine which riverine issues were important to them and access

local knowledge about the chosen study area. Traditional field data collection and processing techniques, and data sets (differential Global Positioning System: dGPS and Electronic Distance Measurement: EDM and laser scanner data, morphological data, flow data, as well as numerical modelling of flow and morphology) were used to investigate the issues raised by a group of interested individuals. The two different types of data were integrated through group discussion and subsequent model development.

Stages and steps	Process	Methods used	Methodology section	Relevant thesis chapters
Stage 1				
Organisational Review				
Step 1	Interviews with current water management organisations (OROs) about participatory approaches	Open ended interviews	3.4.1	4, 9
Stage 2				
Ebchester Study				
Step 2	Developing local project: identifying issues and concerns which could be investigated within the Derwent catchment	Community drop-in session	3.4.2	3, 5, 9
Step 3	Establishing competency group for selected issue (weir restoration at Ebchester)	Drop-in session and focus group	3.4.3	5, 9
Step 4	Developing research objectives and sharing knowledge between group	Focus group, round-table meetings, site visit	3.4.4	5, 7, 8, 9
Step 5	Field data collection for 'scientific' component of investigation	dGPS, EDM, laser scanner	3.4.5	7
Step 6	Data preparation and use of numerical model to investigate issue of weir restoration	GIS preparation and analysis, HEC-RAS model	3.4.5	6, 7, 8, 9
Step 7	Data analysis; bringing together experiential and scientific knowledge to address research objectives	Focus group	3.4.6	7, 8, 9

Table 3.1 Process summary for research methodology. 'Stage 2: Ebchester Study' refers to the interdisciplinary, participatory process which is focused on the River Derwent, County Durham, in the village of Ebchester. The numbers indicated in the 'Relevant Thesis Chapters' column indicate the chapters in which process, findings and discussion can be found for each specific step

3.3 A note on thesis structure

Due to the interdisciplinary nature of the research carried out during this study, a number of widely varying methods were employed (as highlighted in Table 3.1) and were carried out for different purposes. These purposes include: i) framing of the issue as a whole, in the wider research context; ii) engaging participants and identifying issues within a local area; iii) extracting/developing knowledge, both experiential and numerical about the chosen study area, and iv) bringing together the different types of knowledge to address the research objectives set by the competency group, as well as evaluate the role of participation and co-production in river management practice to answer the overall research questions of the thesis.

This chapter will describe the methods used for the wider goals of the thesis and qualitative data collection. Detailed descriptions for the more applied methods (primarily the field data collection and numerical modelling, but also to some extent the collection of experiential knowledge), have been reserved for the appropriate chapters dealing with these aspects of the thesis. This is because of the detailed, technical nature of the processes followed. To include such detail in this chapter would disrupt the discussion of the overall approach and cause repetition within the relevant chapters. Therefore, within this thesis, there are two core methodology sections:

1. This chapter addresses the framing of the issue in the wider context, engaging participants and identifying issues, extracting experiential knowledge and bringing together experiential and numerical data to address a co-developed research objective,
2. Chapters Six, Seven and Eight detail the field data collection techniques and various steps of the numerical modelling process.

A detailed description of the site selected for the Ebchester study site is included in Chapter Five , which provides a review of the chosen case study.

3.4 Research methodology

The primary aim of this study was to investigate the role of experiential knowledge in river research and management processes. In order to frame the localised study and in contrast to its local nature, an investigation of current management and participatory approaches was conducted with water managers from the UK and north-west Europe. The following sections will describe each of the methodological stages and steps, as outlined in Table 3.1.

3.4.1 Step 1: Investigating current participatory approaches in river management

Participants for this study involved members of an EC funded initiative which is investigating the potential for land use changes for flood alleviation (from hereon, referred to as the 'EC group'), as well as a number of water managers from within the UK. Interviews, carried out between October 2010 and October 2011, were conducted with nine water management organisations from north-west Europe. The specific organisations were selected for the study because they all had an interest in flood risk and land management, were at an appropriate stage to evaluate their participatory approaches, and considered the study to be beneficial to their learning about participatory management. Six EC Group partners took part initially and the data were supplemented by three interviews with external OROs, for a number of reasons. First, to provide a view from outside of the EC Group, to cover for any bias implicated by the specific funding offered through the EC Group project for participatory measures. Second, to provide stronger representation by smaller organisations: the majority of the EC Group partners operate at the catchment or regional scale. Finally, to strengthen the UK representation, as this is where the more focused case study was to take place. The interviewees involved are summarised in Table 3.2. Their roles and project characteristics will be discussed in more detail in Chapter Four.

Project number	Organisation type/Interviewee discipline	Country
P1	Regional organisation for water management (WFD, flood risk, permits)management/Ecological consultant	Germany
P2	Regional organisation for flood risk and reservoir management/hydraulic engineering	France
P3	National organisation for water management (flood risk/WFD)/Management and river processes	Belgium
P4	Regional water board/Spatial planner	Germany
P5	Regional water board and waterways management/waterways manager	Netherlands
P6	Regional Water board/Biodiversity	UK
P7	Local NGO/Hydrology and geomorphology	UK
P8	Local NGO/Fluvial geomorphology	UK
P9	Local NGO/Fisheries scientist	UK

Table 3.2 Water management organisations interviewed in Stage 1: Organisational Review, to determine approaches to, and views of, participation in river management at a variety of scales

Prospective interviewees were initially contacted via email by myself or a mutual contact within the EC research group and all of those approached agreed to take part. A semi-structured interview approach was adopted to help steer the interviewees towards providing data relevant to the research questions, but to also allow interviewees to introduce topics that are related but not addressed within the question set. The interviews were conducted in person, either within the working office of the interviewee, or at conference events, but always within a private room, with only the interviewee and myself present.

All OROs were asked the same questions (listed in Appendix C) to ensure an internally consistent approach (Mason, 2002). Responses were audio-recorded, with permission, to ensure all details were captured, and notes were not taken, to avoid distracting the speaker. Questions, which were provided to interviewees in advance to encourage considered responses, were designed to draw information on project context and scale; the specific approach to participation; the respondent's view of the role of participation; the success of participation for their project and the limitations of and constraints on their approach. Additionally, interviewees were provided with conceptual diagrams of Callon's (1999) three modes of participation (as discussed in Chapter Two and illustrated in Figure 2.1). They were asked to, if possible, assign their approach to one of the modes and explain their reasons. The aim of this task was to help gauge their opinion of their level of public engagement (shaped through practice and commercial or organisational controls), which I later critically analysed based on knowledge from wider academic literature and my own observation of practice.

3.4.1.1 Data analysis for step 1

Interviews were transcribed and analysed qualitatively according to a grounded theory approach (Crang, 1997) in which data were coded and assigned to categories. From this, relevant themes and theories about the findings were developed. Recurrent themes were considered in the context of each project and in light of wider understanding of approaches to participation. A cross-sectional approach to data indexing was adopted in order to create and locate interpretive, conceptual, and analytical categories and themes in the data (after Mason, 2002). Interview excerpts were allocated to one or more themed categories and those categories applied to all interviews to allow a just comparison of approaches by different OROs. The data contained in the transcripts were considered both in their literal context (to determine the practices and methods of participation described by each interviewee) and the interpretive context, through which the attitudes of the interviewees toward participation were considered. Categories assigned were considered as literal (e.g. scale of project; official aim of project; approach to/methods of participation used; who was involved; who was affected; success of approach; reason for chosen

approach; level of control/involvement for participants; problems encountered and management of the ORO) or interpretive (e.g. opinions on participation, the approach adopted and its value; who is considered as a 'participant', and advice offered, based on knowledge and experience). For some of the categories, such as level of success, problems encountered and who is considered a participant, there may be data which could be literal and/or interpretive: in such cases, the form in which the data were considered was noted. Where appropriate, the data were also considered as case studies in their own context (for example when considering why a certain approach was adopted by a certain ORO).

3.4.1.2 Subjectivity and limitations in Step 1

Some consideration must be given to the influence of context and interviewer in obtaining these results. Every interviewee will respond differently in the interview situation and to the interviewer. In order to minimise the impact of context and personal interactions, all interviewees were provided with the questions to be asked (which were the same questions, asked in the same way and in the same order to each interviewee) before the meeting. Every effort was made to ask questions in a neutral manner and not disclose personal opinions or reactions to the interviewees. Despite this, a number of the interviewees seemed aware of the type of answers that would be considered most favourable and, on interpreting the data, I found myself noticing that some interviewees attempted to create 'an image' of themselves or their work, which does not match the more factual information they provided, but which they perhaps thought was the answer that I was searching for. To deal with this, where possible, more factual data (such as participatory techniques that were adopted) were considered separately from subjective data (such as which of Callon's models they believed they were aligned to).

Further limitations include a language barrier which I believe caused some of the interviewees to make statements in a way that they were able to articulate in English, rather than say what they truly wished to communicate, while others (the native English speakers) often provided much more elaborate answers. Questions were provided prior to the interview to allow non-English speakers to familiarise themselves with the questions and prepare answers in English.

It is acknowledged that nine is a relatively small sample of all the river management projects taking place in Europe, however, within the constraints of a PhD and narrowed by the organisations who were both willing and able to take part, it is believed that this sample provides an interesting insight to relationships and processes for those groups investigated and point to the issues that may be found by other river management organisations.

Based on some of the findings from the Organisational Review, the second stage of data collection was instigated, in which a small scale competence group was formed to address a specific river reach issue. This is outlined in the following sections.

3.4.2 Step 2: Identifying potential issues for investigation in the Derwent catchment

The River Derwent, which forms part of the border between Northumberland and County Durham, and which flows into the River Tyne, was chosen as the study site for this project because of my familiarity with the catchment from previous research, including some of the issues within the catchment, and the knowledge that some data, such as flow data, which need to be collected over the long term, already exist and are accessible. At the outset, in keeping with a participatory approach (e.g. Pain *et al.*, 2012), no more detailed decisions on specific site location, or issue to be investigated were finalised. These parameters were left open in order to allow a project to be developed which was relevant and useful at that time. By developing a research project *with* a group of participants which has a vested interest in the processes and outcome, the group can be engaged, participation is likely to be long-lasting (Pain and Francis, 2003) and the exchange and production of knowledge becomes more effective (Pain and Francis, 2003; Klodawsky, 2007). To this end, a drop-in session was held in a village hall located centrally within the catchment. The event was advertised through a number of posters placed along the course of the river in village shops, post offices, village halls, recreation sites etc. Adverts were also placed in the local newspaper for the area and on the Tyne Rivers Trust web page, and an information leaflet was produced for distribution to any interested party (Appendix D). The adverts (see Appendix E) invited residents to come to the session and discuss issues and interests, as well as knowledge and information they had concerning the River Derwent. The session was held at Ebchester Village Hall (chosen for its central location within the catchment). Attendees were given the opportunity to label a large map of the catchment, in the relevant location, with any concerns/knowledge they wished to share. Participatory mapping was used because the aim was to allow individuals to express what was important to them, in this specific location, as Henkel and Stirrat (2001, p181) suggest “What all...maps have in common is that they depict what seems important in the cultural context of their production”. Furthermore, maps are an effective way of documenting the spatial dimensions of issues (Kesby, 2000; Pain, 2004) and identifying areas of overlap and issues shared by a number of groups or individuals. The input was recorded photographically and the issues noted (Figure 3.1). The session was also used to make contact with residents of the catchment and to discuss with them on a one-to-one level which aspects of the river were important to them. Other methods used to gauge interest in the River Derwent

included contact with a local river conservation charity, the Tyne Rivers Trust (from hereon, the TRT) who play a significant role in the implementation of rehabilitation and conservation measures on the River Tyne and its tributaries. They have a developed and trusted reputation within the catchment and are familiar with the issues present and those residents who are concerned and pro-active enough to become involved. Through the TRT I contacted a number of residents who were pursuing catchment management initiatives, and also attended a number of country shows and open days with them within the Derwent catchment. At such events I was able to further develop an awareness of the catchment issues through conversations with members of the public, specifically those who use the river for recreation and angling purposes, and to further my understanding of how the river is used by the catchment residents. As a result of the drop-in session, email responses to adverts, country shows and contact with the TRT, a shortlist of main issues in the catchment was created, these issues are described briefly below.

Flooding in Blanchland - Residents of the village of Blanchland (Figure 5.3) raised concerns about the frequency of flooding in the village at a confluence between the River Derwent and a tributary. The residents and spokesperson for the Lord Crewe Estate claimed that they were aware of why flooding occurred so frequently, and could estimate when a flooding event would occur, but that attempts to secure Environment Agency flood defences had failed. A meeting was held with a local NGO to determine whether flood modelling, coupled with a flood action group established in the village (to help to raise awareness and contribute local knowledge of flood events and characteristics) would be able to provide evidence to the Environment Agency that flooding was an issue in this village and should be addressed.

Weir restoration in Ebchester – A 300 year old weir, once used to divert flow towards a mill race in the village of Ebchester has become degraded in recent flooding events. Local residents and river users have a number of concerns around this issue including the falling level of the pool behind the weir and sedimentation rates. There has been ardent campaigning from a small group of residents and river users to secure funding and support for the weir's restoration, which itself has brought about a number of questions and conflicts. The weir restoration interest group was keen to learn more about the potential effects of changing the cross section and height of the weir to both increase their knowledge base, and, if appropriate, support their proposition.

Building on a floodplain at Shotley Bridge – plans and approvals for a new housing development on a floodplain near to the village of Shotley Bridge raised concerns amongst residents who were aware that the area frequently flooded and a number commented that very close to the proposed site, a bridge had been destroyed in the last flood event (2009). The residents suggested that it

was clear that the area was inappropriate for development, yet plans appeared to progress. The residents were keen to investigate and quantify flood risk for the area in order to support opposition to the development.

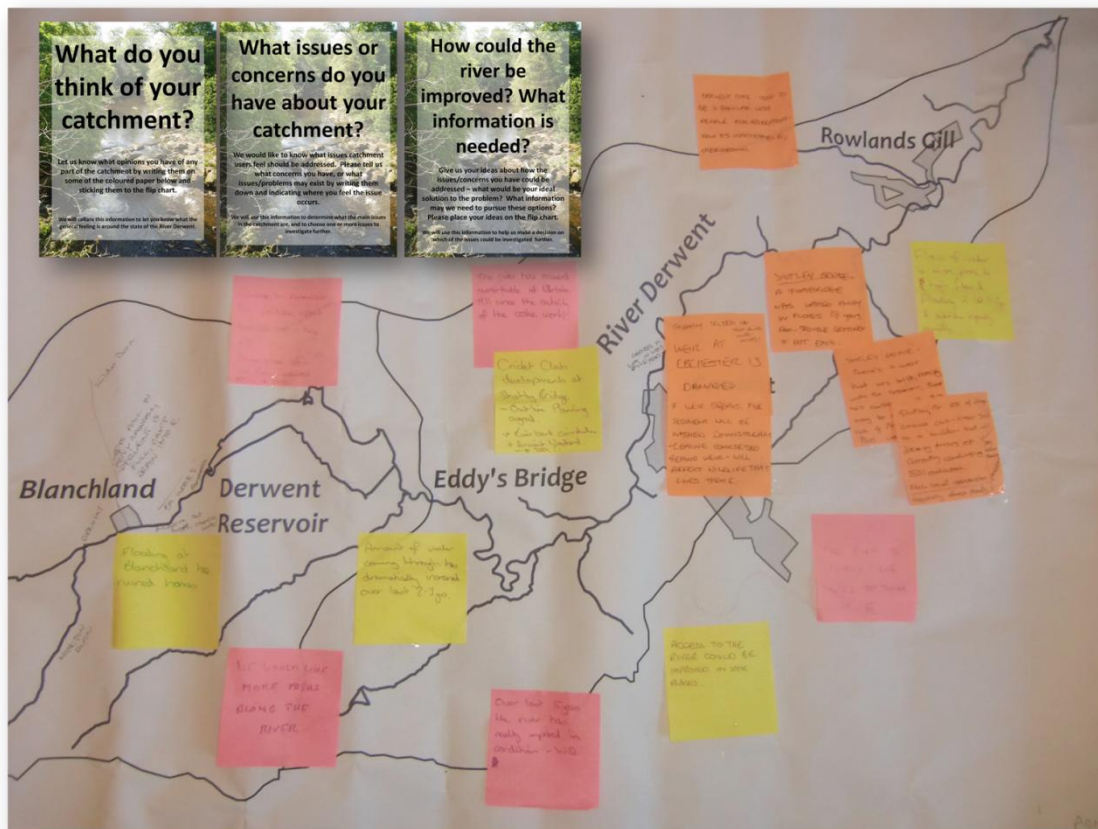


Figure 3.1 Catchment outline map annotated with comments from community members in response to the questions posed at the drop-in session. The posters created to ask questions of the participants are displayed in the top left corner. The smaller text provides more detail about the question, instructions on how to annotate the map, and details about how the information would be used

Initially, it was hoped that two of the above projects could be adopted and developed as part of the PhD. Preliminary scoping meetings were held with the members of the Blanchland and the Ebchester groups, separately. As discussions progressed, however, it became clear that time would only allow to conduct one project in depth, given the mix of social and physical science fieldwork that would be involved. The Ebchester Weir project was selected for a number of reasons. First, a group of interested individuals had already assembled themselves to work towards restoring the weir. This demonstrated their commitment and passion for the cause and, as noted by Pain and Francis (2003): “Where participants are involved at the stage of problem

definition and research design, participation in later stages is more likely. This is generally easier where a group with some formal structures already exists.” Second, The issue of flooding, experiential knowledge and campaigning for change has recently been investigated (Lane *et al.*, 2011). Therefore, investigation of the impacts of restoring a weir will build upon this recent call for the use of local knowledge in river management research, providing the perspective of a case that is less fundamentally controversial (in terms of risk to peoples’ livelihoods and homes), but of great interest and importance, socially, to those involved. The difference between the severity of these two issues (flooding and weir restoration) could be the difference between the effectiveness of the approach and will help to answer the question: will local experts be truly engaged when the issue is a matter of interest (or leisure) rather than a matter of home and livelihood? Finally, flow and (some) morphology data for the River Derwent downstream of Derwent Reservoir exist and are accessible, whereas scientific data upstream of the reservoir are more limited (there are no flow records of the unregulated reach of the stream). This would have limited the extent of investigation in terms of flow modelling and the outcomes achievable in the timeframe of a PhD study would be of limited benefit to the community. Therefore, the weir restoration project was selected as the case study for this thesis.

3.4.3 Step 3: Establishing a competence group to investigate the selected issue

The founders of the group in Ebchester agreed (and were keen) to take part in the PhD study and suggested other potential members for a competence group, which from hereon will be referred to as the Ebchester Weir Restoration Group (EWRG). Members of the group were also found through the drop-in session and contacts made via the TRT. These members were approached and all but two agreed to take part in the investigation, forming a group of 12 members, including myself. The project was offered to the group members as “an opportunity to share knowledge and concerns in order to investigate the potential impacts of weir restoration in Ebchester by combining local, experiential and scientific knowledge through traditional (scientific) and contemporary (social) methods”. In return for their participation, the group were promised a number of things:

- A research project developed together and based on research questions formulated by the group;
- Sharing of knowledge and production of new knowledge of the weir, and the river, in the village of Ebchester;
- An open and respectful environment in which all members were free to offer information and raise questions, as they felt appropriate;

- Updates on developments as the research progressed and the opportunity to review the research results as they were produced and a primary role in the making of conclusions;
- Discussion of the outcomes and their implications for the EWRG.

It was made clear to the EWRG that through this study I could *not* promise the following:

- To answer/solve all of the issues discussed;
- To bring about changes in policy or the restoration of the weir.

Clarifying what is and is not possible at the outset is an important aspect of expectation management. It is essential to ensure all parties are aware of what can and cannot be achieved in order to build trusting relationships and confidence in the process (Hansen and Maenpaa, 2007).

3.4.3.1 Competence group members

The EWRG consisted of 12 members, including myself. For purposes of anonymity, each member has been assigned a code, along with an outline of their interests, in Table 3.3. The members represent a range of interest groups, but all have a personal interest in the Ebchester weir. There were a number of conflicting interests within the group.

Member Code	Affiliation (where applicable)	Interests
M1	Founder of initial interest group around weir restoration	Ecology, habitat, aesthetics and heritage
M2	River management organisation	River rehabilitation, conservation, public engagement
M3	Village resident	Village heritage, aesthetics, recreation area
M4	Sea Scout instructor	Use of river for youth activities and recreation
M5	Local Resident and local business owner	Village culture and history, used to be part of village rowing club and was organiser of a number of regattas held on the river in past years
M6	Angler and angling instructor	Fish habitat and fish passage. Types of fishing available on the river. Wider habitat and ecological interests
M7	NA	Local interest, biodiversity
M8	NA	Local interest
M9	Local resident living in close proximity to the weir	Flooding. Use of river for recreation and implications of increased use, such as parking
M10	Local resident	Flooding, public use of river area
M11	Local resident	History of river, cultural aspects of river use, biodiversity

Table 3.3 Members of the initial competency group, their affiliations and interests driving them to act for change on the River Derwent

In choosing individuals to be part of the competence group, there is a risk that certain interest areas will be overlooked, or that interested parties will be excluded. In this study, it was fortunate that the number of people who approached me about the project, as well as those that I approached through the TRT was in the optimum range for this kind of work (between six and ten participants is recommended in order to balance diversity of perspectives while avoiding fragmentation; over-recruitment of 10-25% is suggested, to account for non-attenders (Rabiee, 2004)). The individuals involved also bring to the group a wide range of interests and knowledges about the river, representing some of the main uses. Interest groups that were not formally represented include those with knowledge of riparian wildlife – an individual with a keen interest in this area was invited to join the group on two occasions but did not respond. As there are a number of angling clubs on the river and they cover different aspects of the sport, members of these groups were invited but also showed no interest. The member of the EWRG who had an interest in angling (M6) participated for his own personal interest and is not a member of any of the official Derwent angling clubs. However, the project was not necessarily hindered by these absences. As Callon (1998) notes, one of the essential criteria for members of groups aiming to create knowledge together is that they are willing and enthusiastic. Furthermore, from a participatory perspective, locally generated issues (i.e. by those with an interest or cause, rather than top-down) are more likely to be engaging to those involved, and therefore productive in developing knowledge and action.

3.4.4 Step 4: Developing research objectives and sharing experiential knowledge

A number of meetings, of various formats, were held with the EWRG. These are outlined below:

CG 1: Preliminary discussion of project and presentation of issues on the river- The meeting was held with four main aims: i) to present to the members, in detail, what my idea for the research project was; ii) to determine what the members wanted/expected and to ensure that there were no contrasts in expectations/hopes for the project; iii) to establish the issues/concerns around the weir and associated river reach and iv) to begin to gather information that the members of the group could offer around the condition and processes of the river (this is discussed in more detail in Chapter Five). The meeting began with a structured format in which I outlined my expectations/interests. I then asked each member to introduce themselves and briefly explain their interests in the river/project. Members were also asked to bring to the meeting photographs, documents, maps etc. which would help to encourage discussion of the river. As

the conversation became more natural and members grew in confidence, the structure was abandoned and the group was allowed to converse freely. This was done to allow the expression of issues and concerns (and also knowledge) of the group which was open and creative. The meeting was held at the home of one of the major activists in the EWRG and was audio recorded with two devices in order to collect all aspects of the conversation. The recordings were subsequently transcribed.

CG 2: Joint meeting with Durham County Council, EWRG and myself. Durham County Council pledged some financial and technical support for the weir restoration, pending surveys and negotiations of requirements with the Environment Agency. The aim of the meeting was to allow Durham County Council to update the EWRG on progress made in discussions with the Environment Agency and discuss plans for the approach to potential weir restoration. Minutes of the meeting were recorded and distributed by a member from the Durham County Council Group.

A meeting was also held between the project coordinator for Durham County Council, and myself, the aim being for each of us to share our ideas and approach to the study and to ensure that the group members were not being asked to repeat activities for different organisations, in order to avoid participation fatigue.

CG 3: Field site visit – with a number of the group members. The aim was to further discuss concerns for the river, knowledge available and finalise the EWRG research objectives. Information from this meeting was recorded through notes and photographs (taken by a member of EWRG) and written up by myself immediately following the meeting. It was particularly important in this case to confirm with the group members that the details recorded were correct. The research objectives for the project were written up at this point and sent to all members for approval. Members were given digital cameras and asked to take photographs in order to highlight which of the areas/features were of significance to them, to be discussed afterwards. While a small number of the members took on this task, most were reluctant to do so and instead preferred simply to chat with me, using the landscape as a prompt. I also assembled some of the preliminary data collection equipment (dGPS, see Section 7.2) prior to the meeting and showed the group members how it was used, and described what I would do with the data. Understanding what kind of data were being collected and how they could be used helped the group to offer questions and ideas for investigation, which were subsequently developed into research objectives for the project (the EWRG Objectives).

After each meeting, notes on what had been covered and, specifically, questions that had been raised were emailed to all members and they were asked to notify me if there were any aspects with which they disagreed or felt needed further consideration.

3.4.4.1 Ebchester Weir Restoration Group's Research objectives

The research objectives that were formulated will be discussed in detail in Chapter Five, but are outlined here to provide context to the next section of the methodological description. There were some questions raised by the group that could not be addressed within this study, although they have been included in this list (in italic) to provide a full representation of what was of importance to the EWRG. What was achievable and what was not was made clear to the group members from the outset. The objectives proposed by the group include:

- Determine the impacts of the shape of a newly restored weir on water level upstream and downstream of the weir. **Questions raised: Would it make enough difference for the work to be worthwhile? Would it increase the available usage of the pool behind the weir for boating activities?**
- Investigate the impacts that could be expected if members of the community were to dredge silt that accumulates behind the weir
- Define the impacts that a restored weir would have in comparison to a weir that was allowed to degrade further. **Question raised: What would happen if we did nothing?**
- Determine implications of removing bar and channel vegetation downstream of the weir. **Question raised: Can I model what effect there would be on flow and sediment deposition if there was less/no vegetation on the weir?**
- *Exactly what work is going to be done by the contractors to fix the weir? Half of the weir is in a conservation zone.*
- *Will relevant parties (e.g. landowners) be informed of the works that are to take place?*
- *To determine how much water will be required to maintain the fish pass, how this would affect the overall water level behind the weir, and whether it would leave potential for hydro-power? Question raised: Can I take flow readings to determine the current distribution of water over the weir? And then develop a water budget for all of the above features?*

3.4.5 Steps 5 and 6: Field data collection and numerical model preparation/application

Given the issues involved, and the hypothetical nature of the EWRG's research objectives, a modelling approach was chosen in order to determine impacts of weir restoration on flow level and distribution, local river bed morphology and impact of vegetation removal.

The model chosen was HEC-RAS, developed by the US Army Corps of Engineers, and widely applied in industry practice (including by the Environment Agency) for 1D prediction of flow conditions within a river and/or reach, in order to address Section 105 of the 1991 Water Resources Act. Boundary conditions of geomorphology and flow are required for this model. To this end, a digital elevation model was created from elevation data collected from the field site between 2011 and 2012. Along with archival flow data recorded by the Environment Agency, the DEM was input to HEC-RAS as a series of cross-sections, and simulations based on varying weir profiles were performed. Due to the detailed nature of model set up and applications and the fact that preliminary results are used in the process of model development, these steps are discussed fully in Chapter Seven, with a review of the use of hydraulic modelling in river research provided in Chapter Six. A general review of the use of models as part of a participatory research process is provided in Chapter Two (2.2.5.1) and discussion of the degree of success of model use in this project can be found in Section 9.5.

3.4.6 Step 7: Integrating experiential and scientific knowledge to address research objectives

CG 4: Presentation and discussion of preliminary results, model practical session - Using a focus group style format, the preliminary model results were presented to the competence group through a PowerPoint presentation which summarised the approach used in data collection and model development. The presentation then worked through each of the model applications in detail, based on the original EWRG objectives developed in Step 4. The preliminary results for each research objective were presented and discussed within the group. A new list of objectives was created, which allowed subsequent model development, based on the group response to the model, the data and the preliminary results.

Following the presentation of results, the model was run so that the group members could experience the process used in the research. After the model run, the results, as presented by the model, were presented to the group, who were then able to request views of results in varying locations, formats and in response to varying parameters. This approach was intended to help the whole group visualise the core working systems and the dynamic nature of the model, rather than being presented with results which appeared fixed and final. In this session, the issue of

uncertainty (in the model and in the data) were discussed in order to ensure that all participants had the same understanding of acceptable and unacceptable uncertainties.

Following CG4, the input parameters for the model were developed further and a number of the original EWRG objectives were re-assessed. Results were communicated to the group via email in the form of a PowerPoint document and comments were welcomed.

3.5 Limitations to approaches

There were a number of drawbacks and limitations associated with some of the methods, and where these have had significant impact on data collection/analysis, they will be discussed in detail in the appropriate chapter. Only an outline of the main issues is provided here.

The first scheduled drop-in session had to be cancelled due to snow, and this happened on the day of the event. People who had attempted to attend this session may have been discouraged from attending the next one because of this. The replacement session happened three months after the initial meeting's date due to a combination of factors including severe weather, person and venue availability. Weather conditions on the night of the drop-in session were poor and this may also have affected attendance levels. It may also have influenced *which* people were present – many of those present were from the village of Ebchester itself, who did not have to travel far (this may also have been an impact of the meeting location, regardless of weather conditions). If this exercise were to be repeated, more publicity would be used to ensure that all interested parties were aware of the event. Holding the same event more than once (e.g. one meeting on a weekday evening, and one at the weekend, and potentially in different parts of the catchment) would also provide greater opportunity to attend if participants have other commitments.

Some members of the EWRG were already in negotiation with Durham County Council regarding the weir restoration before my project began. For some members of EWRG, the predominant concern was to secure weir restoration and my research was solely an avenue to achieve that goal. This meant that as work with Durham County Council progressed and the weir restoration was secured, some members did not wish to continue with the EWRG. However, the most active and dominant members remained interested in the process even once the weir had been restored. Durham County Council announced that the weir would be restored during the project, however, relevant geomorphological data were collected before the changes took place.

Arranging competence group meetings was a time consuming process which caused the start of the project to be slow and delayed progress in data collection. It was very difficult to find timeslots when all members were available and on some occasions this meant that meetings had to go ahead with some members absent. There is a chance that this can change the dynamics and focus of the meeting, to be dominated by the interests of those present. I attempted to minimise this effect by ensuring all members received the notes from the meetings and those who were absent were given the chance to comment on what had been said.

Physical data collection for input to the model was more complicated than originally expected due to factors such as equipment difficulties and river accessibility due to flow levels and took over a year to complete. Coupled with the slow progression of the competence groups, this resulted in a delayed start to the modelling process. This had implications for the project in terms of maintaining interest over long periods that were relatively fruitless (for the participants). The implications of this are discussed in detail in Chapters Eight and Nine.

3.6 Ethics

Ethics in participatory research must adhere to standard ethical requirements (such as respect for persons, beneficence and justice, as set out by The Belmont Report (National commission for the protection of human subjects of biomedical and behavioural research, 1979)), but must also extend beyond these requirements in order to embrace the principles upon which it is based. There are some aspects of participation which have direct implications for ethical decision-making, which include: representation, accountability, social responsiveness, agency and reflexivity (Manzo and Brightbill, 2007). In aiming to accommodate these principles, participatory researchers may be required to move away from the standard ethical protocols and adopt a process termed by Freire (1988) as 'conscientisation', or, the development of an informed critical perspective among participants (Manzo and Brightbill, 2007). For example, the particularly reflexive and dynamic nature of participatory research means that it is not possible to fully anticipate the ethical issues which may present themselves throughout the course of the research, when ethics are being considered at the outset. This example demonstrated itself in the present project when priorities concerning the initial EWRG objectives changed in response to the preliminary model results and the loss of members from the competence group. The remaining group members were left with the decision of whether to continue investigating research objectives that had initially been proposed by now absent group members, or to pursue new interests. In this case, it was decided that due to the late stage of the project, and for

completeness, the initial EWRG objectives would be addressed in the model development. Therefore, the avenues of research that were agreed with the original group were explored, as promised at the outset, despite the loss of some group members.

Another aspect of participatory research which differs from traditional approaches is that of anonymity (Manzo and Brightbill, 2007). By working with a mixed group, in which members voice opinions, knowledge and concerns openly within that group, and furthermore, the group then deliberates upon points presented, anonymity of views cannot be offered. To deal with this in the Ebchester Study, the group were provided with clear instructions about how their input would be used (and the goals of the project), and were asked to state their consent at the outset. Beyond the focus group session, anonymity could be provided by assigning group members with a number rather than using names. Similarly, in the Organisational Review, the interviewees took part not only to provide research data, but so that they could also learn from other interviewees about participatory processes (via a document prepared by myself, promised in return for the input of their time). Anonymity therefore was again not possible within the group of interviewees, but the interviewees had agreed to, and utilised the situation. Any discussion within this thesis, and beyond, anonymises the interviewees.

3.7 Chapter summary

This chapter introduced and described the methodological approaches taken in order to deliver the Organisational Review and the interdisciplinary, participatory Ebchester Study. The approach to creating an environment in which new knowledge may be co-produced was outlined, starting with a drop-in session to identify the issues within the wider catchment, the reasons for the selection of the project that was to be carried out, the engagement of competence group members and the way in which the EWRG research objectives for that study were developed within, and by the group as a whole. The importance of this for a unified group, a focused project and effective outcomes were discussed. The physical field data collection processes were briefly introduced and are discussed fully in Chapters Six, Seven and Eight. The process by which the various knowledges were integrated is described and the chapter ends with a discussion of the limitations and ethical implications of the whole process, with particular reference to the participatory aspect of the research.

A number of social science methods were employed at various stages within the project, which included open-ended interviews, participatory mapping, community drop-in sessions, focus

groups, site visits and round-table meetings. The selection of each method for the specific aspect of the research requires careful consideration and reasons for selection have been highlighted within the process description.

The following chapter enters the next part of the thesis which is concerned with the findings of the Organisational Review. Following this, the Ebchester Study is presented in detail, from the initial knowledge sharing stages, through data collection, model preparation, developments and application, the response of the competence group to the preliminary model results and subsequent development.

Part II:

Review of organisational
practice

Chapter Four

The Organisational Review: approaches and barriers to participation in river management

4.1 Organisational context

The recognition in recent years of the need for a participatory approach to river management was introduced in Section 2.2. However, adoption of a purely scientific approach to river management strategies persists in many cases and can lead to the alienation of, and resentment by, those directly affected by changes implemented (Junker *et al.*, 2007). There is increasing support for a higher degree of involvement of river users and communities in making catchment management decisions (e.g. Cook *et al.*, 2012), as discussed in Chapter Two. Within the relevant literature there are varying theories based around what level of involvement is appropriate in certain situations (see Section 2.4.1), and this theoretical debate extends into practice as public engagement is carried out within public agencies in a number of ways and to varying degrees (Walker, 2004). Despite the growing calls for, and attempts at, public participation, it has been suggested that truly deliberative public engagement is still the exception rather than the rule (Petts, 2007), and Pahl-Wostl *et al.*, (2011) argue that real transformations of water management principles and practise are yet to be realised.

This chapter begins with an outline of the regulatory pressures on water management organisations ('ORO' refers specifically to organisations involved with the Organisational Review) and the issues associated with the limited guidance offered around certain aspects of participation (such as who to involve and to what level). The rationale and approach taken for the Organisational Review is then briefly presented and followed by a description of the findings. The

findings are organised according to a number of emergent themes from the research, namely the approaches and attitudes to participation (Section 4.3.1), the impact of scale (Section 4.3.2), ORO's motivations, goals and context and the effect of these aspects on approaches to participation (Section 4.3.3), and the use by some OROs of the participatory process as a resource when time, funds and equipment are limited (Section 4.3.4). This is followed by a discussion of the constraints on river management organisations which impede the co-production of knowledge, in relation to the knowledge production model outlined by Callon (1999). Finally, a revised version of Callon's knowledge production model is suggested in order to account for some of the limitations that have been highlighted through this study.

4.1.1 The issue of participation for river management organisations

Within the environmental management sector, statutory bodies, charged with the responsibility of making efficient decisions around catchment management approaches, are increasingly instructed to include 'the public' in planning and decision-making for river management. At the forefront of catchment management legislation in the UK and Europe is the EU Water Framework Directive 2000/60/EC (EC, 2000), which requires competent authorities to provide information to, and consult with "all interested parties" (EC, 2000: 1916), particularly in the production and review stages of River Basin Management Plans. Supporting this is the ruling of the Aarhus Convention (1998), which aims to draw a link between *environmental* and *human* rights and proposes that sustainable development can be achieved only through the involvement of 'all stakeholders'. Despite the requirement for catchment managers to engage in participatory practices, there is ambiguity around the exact way in which this should be approached. Although the WFD provides a substantial guidance document on the different approaches to and methods of participation (EC, 2003), it does not dictate which approaches should be adopted and when. It states that the 'information provision' and 'consultation' aspects of participation must be carried out, but higher level methods such as 'engagement' and 'co-decision-making' are not obligatory (Henriksen *et al.*, 2009). Further to this, there is no specific guidance on who should be involved. The guidance on participation (EC, 2003) suggests that 'any interested party' should be involved, but also notes that it is impossible to involve all individuals with an interest, so a stakeholder analysis must be conducted to aid selection. The Aarhus Convention claims that sustainable development can be achieved only through the involvement of all stakeholders, although the term 'stakeholder' is not defined. Furthermore, while the Aarhus Convention speaks of authorities 'considering the outcome of public participation in their decision', it suggests that 'the public concerned must be informed of the proposed activity early in the process' – suggesting that

the power held by the public remains limited and the final decision lies with the authorities, rather than the authorities and the public developing questions and strategies together.

Consequently, organisations are left to determine who they consider to be relevant participants and what degree of involvement is appropriate within the context of their project (as well as within the remit of the project, and the funding available). There is currently little guidance on which methods of participation work in which frameworks (Wheaton *et al.*, 2006) and the requirements of legislation such as the WFD and the Aarhus Convention 'raise a need for guidance on exactly how the public is to be involved' (Welp, 2001). Cumulatively, this can result in an inconsistent approach to river management, contradictory to the aim of the WFD, which is to achieve consistent ecological goals across Europe.

4.2 Conceptualising approaches to participation and catchment management

Approaches to participation and their discussion are abundant, and have been considered in detail in Chapter Two. The process of co-production is currently popular within Science and Technology Studies literature and its benefits have been proffered by many authors (including Gibbons *et al.*, 1994; Callon, 1999; Whatmore and Landström, 2011). Many approaches to participation in river management literature are reflective of at least one of the three models of participation described by Michel Callon (1999) (discussed in Section 2.3.5 and see Figure 4.1). In order for Callon's co-production of knowledge model (CKM) to be effective, it is logical that public engagement must operate at the local/reach scale. However, it is rare for river management organisations to be able to operate at this scale, and counter-intuitive to the drive in recent years to consider catchments holistically. This broad scale study aimed to assess the approach taken by a number of river management organisations in the context of these models, to determine whether high degrees of public involvement are (or can) be used beyond the reach scale. Callon's framework was chosen because it focuses on the nature of 'the divide between specialists and non-specialists', and pays specific attention to the 'degree of involvement of lay people in the formulation and application of knowledge, on which decisions are based'.

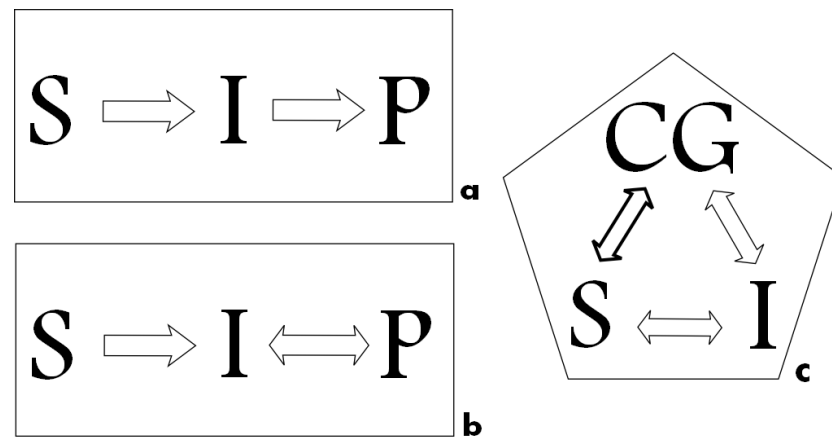


Figure 4.1 Models of participation (after Callon, 1999), previously presented in Section 2.3.5 : a) Public Education Model (PEM); b) Public Debate Model (PDM); c) Co-production of Knowledge model (CKM). Where: S = 'Scientists', I = Intermediaries, P = 'Public', CG = Concerned Group The double-ended arrows denote two way communication, while single-ended arrows denote a linear flow of information. The heavier arrow in image 'c' indicates the dominant relationship

Interviews were conducted with the nine river management organisations listed in Section 3.4.1 to investigate the current approach of river managers to participation and identify differences between projects on varying spatial scales whilst considering how effective the process is when accounting for managerial constraints (see Appendix C for interview questions). The type of organisation, and the aim, geographical scale and timescale of the projects considered are summarised in Table 4.1.

Project number	Organisation type/Interviewee discipline	Project scale	Project aim	Project timescale	Participation activity timescale
P1	Regional organisation for water management (WFD, flood risk, permits)management/Ecological consultant	CATCHMENT+	Flood protection, natural storage, improved drainage, ecological flooding	Early 1970s - ongoing	Started at discussion of site locations, early 1990s – ongoing.
P2	Regional organisation for flood risk and reservoir management/hydraulic engineering	CATCHMENT+	Flood protection, floodplain restoration, ecological flooding, landscape integration	Pre-2000 - ongoing	Started with design phase, year 2000. Ongoing
P3	National organisation for water management (flood risk/WFD)/Management and river processes	CATCHMENT	Floodplain expansion, farmland protection, meander restoration	2000 - ongoing	Started with WFD consultation, 2006
P4	Regional water board/Spatial planner	SUB-CATCHMENT	Strengthen dyke, controlled flooding, channel widening, ecological benefit	2001 - 2013	Some participation between 2003-2011, official participation period 2006-2007
P5	Regional water board and waterways management/waterways manager	SUB-CATCHMENT	Flood water storage, relocation of farming families, ecosystem restoration	2001-2015	From outset until time permits granted
P6	Regional Water board/Biodiversity	SUB-CATCHMENT	Improved water quality and biodiversity, reduction of carbon release, sustainable farming	2010 - 2015	Once management plans were decided upon
P7	Local NGO/Hydrology and geomorphology	REACH	Reduction of flood risk and low flow events	From 2005 onwards. Ongoing	Once project had been formulated with other environmental managers and researchers
P8	Local NGO/Fluvial geomorphology	REACH	River rehabilitation, improved fisheries, pollution prevention, flood prevention/control	Variable. Short-term (up to 2 year projects)	Depends on project. Public approaches NGO, otherwise, very early in process : at design stage
P9	Local NGO/Fisheries scientist	REACH	Fish passage, river restoration, education, engagement	Variable. Short-term.	Spoke to local interest groups once some basic design work completed

Table 4.1 Interviewees involved in the Organisational Review of approaches to participation

4.3 Study findings

The findings highlight the important role of the 'local expert' in the participatory river management process. The 'local expert' is defined as an individual who has traditionally been classed as part of 'the public', but who can be set aside from the wider public by their local experiential knowledge of a project or place through regular personal interaction with the river system, such as farming, angling, recreation or volunteering. Local experts may collectively form a 'concerned group' (Callon, 1999).

4.3.1 Approaches and attitudes

Despite the varying range of ORO aims, sizes and remits, it initially appears that there are many similarities between the OROs, in their approach to participation. Most approaches consist of the initial development of an idea, with local experts and the public being involved once the initial remit is established. In cases where the general model was to involve local experts or the public in aspects of design and gauge opinion of a project, there were a number of standard approaches to communicating with the local experts and the wider public which include information events, drop-in or question and answer sessions and newsletters. Where the project required input of technical knowledge or opinion from local experts or stakeholders there were usually more interactive processes such as workshops or round-table talks. Some less common approaches included local juries and technical workshops (e.g. for numerical modelling). The degree of participation was very much dependent on the stage and nature of the project. Some projects involved in-depth participatory procedures in which selected local experts had control over technical elements, although most projects appeared to allow the public and stakeholders to comment upon aspects such as design, but not contribute knowledge to technical or scientific plans. Where greater degrees of involvement were used, success of the participatory approach moved beyond an increased support for the project, to an active desire on behalf of the public, local experts and stakeholders to be involved and contribute to the project.

When asked to consider their approach to participation in the context of Callon's models, the interviewees demonstrated a range of interpretations. Few were able to definitively assign themselves to one of the three models, suggesting that degree of local expert or public involvement was dependent upon project stage and how the model's groups were defined. Interestingly, it was those interviewees whose projects had in-depth local expert involvement who considered themselves to be utilising the public debate model (PDM), rather than the CKM, and acknowledged room for improvement. All interviewees believed the CKM was the 'optimum'

approach and what is expected in current legislation, but few felt they achieved it in their work. It was suggested that different models might be appropriate for different types of problem. To illustrate, one interviewee used the example of flooding, suggesting that the CKM would be effective in managing flood risk, where local knowledge of how rivers and floodwaters behaved in a certain area could be combined with 'scientific' knowledge of connectivity, flow routing and appropriate mitigation measures.

Despite the variation in levels of involvement achieved, most OROs believed that they were taking the optimum approach for their specific project, but that given the opportunity, would invest more financial and temporal resources into the participatory process.

4.3.2 Scale

Although it appears at the outset that approaches used are similar for most OROs, it became clear through the development of themed categories that there were distinct differences in attitude to, and success of, participatory measures. Underlying this distinction was one dominant constraint on the *degree* of participation used by OROs: *project scale*.

The project remits for the OROs have been assigned to three different scale categories: reach, sub-catchment and catchment or above (Table 4.1). The findings show that degree of participation is inversely related to project scale. It was found that reach scale projects (Projects 5,7,8,9) generally included the greatest degree of participation, with particular reference to the amount of control local experts were given over technical decision-making processes. In Project 7, local experts and scientists worked closely together. The local experts were allowed to suggest and reject land management options for slowing down overland flow and increasing water storage on land. Local experts and scientists worked closely when proposing and selecting management options and both groups attended all meetings and workshops in which decisions were made. Similarly, but to a lesser extent, Projects 8 and 9, whose work is primarily based around river reaches, or small community areas, called upon the knowledge of the local population to identify appropriate management foci. Local knowledge was used to inform decisions regarding which management changes should be undertaken, and how, thus providing the participants with a sense of empowerment and ownership.

Project 5 presents an unorthodox example in which the local farming community potentially affected by flood water storage plans approached the government with their own proposals and requests, in return for them willingly offering up the land for project use. As a result of their proactive involvement, the families were given increased flexibility over the changes made:

“...I think a lot of [the] conditions were met... Of course, not all of them, it’s not possible but I think especially for the farmers, they really came out well.” (Project manager, P5)

This level of interaction and bargaining was possible because the group consisted of a manageable number of families (17) and it was noted that the outcome would not have been possible at a larger scale. The situation of this group lies somewhere between Callon’s PDM and CKM. The group did not help to produce new knowledge, but were afforded some control over the decision-making process: their input was not used simply to ‘enhance the official expertise’. All four organisations working at the reach scale (Projects 5,7,8,9) reported good success rates for their projects and attributed success to the integrated work between traditional scientists and local experts.

While the larger scale projects (sub-catchment, catchment and beyond) clearly made an asserted effort to involve those affected by the processes, involvement was often limited to information provision and consultation. When local experts and the public had a greater degree of input, this was usually confined to design aspects, and local process knowledge held less weight in the decision-making process. For example, Project 2, in which great efforts were made to be open and accessible to the public, with the use of information events and an ‘open house’ in which questions and concerns can be addressed by those managing the project. The project managers even allowed those who would be affected to have a great deal of control over where large floodwater storage compartment areas would be built. However, the overall approach to flood water storage was decided upon before the public were involved and public/local experts only had the opportunity to contribute within fixed boundaries, indicative of Callon’s PDM:

“the consultation started immediately at the same time as the design [of storage compartments] phase” (Project manager, P2)

In Project 4, a ‘local jury’ was created, charged with the task of selecting a design plan for the reclamation of floodplain along an 80 km stretch of an urban river. However, the panel were presented with a number of pre-defined options from which to select, and had no input regarding the technical aspects of the engineering work. It was noted that the approach taken allowed the project to be publicised, allowed members of the public to ask questions concerning them, and gained support for the work through media coverage (reflective of Arnstein’s ‘Placation’, or Pretty *et al.*’s (1995) ‘Functional participation’, in which participants are given the chance to voice their opinions around set topics, but are afforded little control overall).

The success of the smaller OROs in achieving effective results through a higher level participatory process is reflective of the proclaimed benefits of the approach. Two of the most important effects include a) reduced uncertainty and validation of process assumptions (e.g. Welp, 2001; Clark, 2002), and; b) the development of trust in both the knowledge produced and the project taking place (e.g. Henriksen *et al.*, 2009). Scale plays a large part in achieving these effects. For example, experiential knowledge, while detailed, is often based around a small area (in which the local expert frequently spends time), therefore assumptions about processes occurring in that area can be validated through experiential knowledge, but not necessarily scaled up for application to (sub-) catchments. The close working of scientists, local experts and members of the public is essential for trust to be established (see Clark, 2002). Therefore, in large scale projects, when communication with large numbers of people is fraught with impracticalities, interaction becomes less personal and the issue of trust recurs. Further to the practical benefits of working closely on a small scale, there are characteristics associated with small scale river managers (such as charities and some NGOs) which encourage them to use participation as a matter of resource management. Such characteristics include severely limited funds which inhibit data collection to the level required, and time constraints which hinder the implementation of practical measures, as noted by the interviewee for Project 8. As a result, such river managers use local expert knowledge to direct them to specific problem areas, verify model findings or ‘official’ understanding of the river system and to engage and involve local people so that they are willing to give their time to both scientific investigation and practical implementation of management processes. All of the NGOs that were interviewed spoke of local experts and the public as essential members of their organisation, who assisted them with challenges in a number of ways and viewed their input as a resource to be appreciated and utilised:

“[our approach is] part of the way of working..... So these ‘citizen scientists’ really are feeling good about learning how to do the work, but they are absolutely crucial to our survival” (Director, P8)

They also tend to have a greater deal of flexibility in how they carry out projects and are less likely to have to apply processes regionally or nationally. This allows them to consider each specific project in its own context and realise the value of local and specific information, which according to Callon (1999, 89) is part of the dynamic of knowledge that should be strived for through co-production.

4.3.3 Motivations, goals and contexts

The interview responses showed that the reason for doing participation and ultimate project aim impacted on the approach to, and success of, the participatory procedure. The most common

purposes for including stakeholders or local experts appeared to be to gain knowledge and information on boundary conditions, as well as gauging the potential response to the project from wider groups. Many projects experienced similar problems and the main ones were related to time, money, power to instil change, will and scale. Constraints beyond the category of resources include dissatisfied stakeholders or participants, expectation management, conflicting interests and the unreliability of some participants. Inconsistencies in staffing and introduction of new staff during projects were noted as administrative constraints. The very act of doing participation was also seen, at times, to detract from the initial goals of projects.

The projects which included participation for reasons such as: benefiting those affected by changes, allowing the local experts or stakeholders to provide individual and diverse expertise, and encouraging local experts and the public to take ownership of a problem or a project (rather than simply to increase project acceptance), experienced positive and pro-active feedback from those involved. Many interviewees noted the efforts made to provide information and to answer questions about planned works was sufficient to increase support for projects and assisted in helping the public to understand why specific measures were needed and what changes would take place.

The background, training and working context of each of the OROs and interviewees may also impact upon the approach taken. Projects associated with flood protection mostly had low levels of public involvement (and were primarily undertaken at the sub-catchment/catchment scale), while those projects more strongly linked with rehabilitation/habitat had higher degrees of participation and were generally reach scale. This suggests that scale may impact upon the kind of work carried out by an organisation. Most projects with a focus on flood defence had poor involvement of local experts while projects based around rehabilitation and habitat improvement included more knowledge from local experts. However, this relationship was not consistent throughout the study and so another parameter must influence the role of project context in utilising participation. Most of the flooding projects operated at the catchment/sub-catchment scale, while the rehabilitation/habitat projects were more associated with the reach scale. However, Project 7 focused on flood prevention, but the ORO and research operated at the sub-catchment/reach scale and involved a number of local experts in decision-making and knowledge production. While the catchment scale flooding projects were developed around hard engineering solutions (e.g. channel reconstruction), the reach scale habitat/rehabilitation projects employed 'soft' engineering measures (e.g. vegetation planting). Project 7 was the exception here as its main focus was flood protection, despite it working at the reach/sub-catchment scale

and having the greatest degree of public involvement. Although dealing with flood risk, this project applied soft engineering solutions to the problem. The use of soft engineering (at reach/sub-catchment scale) makes the process of participation more accessible because local experts and the public may have knowledge of how localised changes may impact the area, as well as being able to become involved in implementation and maintenance. There was also a link between the expertise of the project managers and the geographical scale of their projects. Project leaders in the large OROs were primarily spatial planners, engineers or catchment managers by profession, whereas in the smaller OROs, specialisms included hydrology, geomorphology and fisheries, which often focus on a more localised scale. Therefore, the results suggest that a combination of project scale and project/organisation context are likely to impact on degree of participation.

4.3.4 Participation as a resource

There are clear constraints on large scale projects which will impede participatory processes, such as the impracticality of speaking to all interested parties and coordinating all sources of knowledge. Furthermore, time necessary to involve local experts or the public to this degree at the catchment scale would rarely be supported financially. However, it appears that constraints linked to the spatial scale of a project go deeper than this. Large river management groups are characterised by hierarchies of management and the power to make changes to procedures rarely lies with those who might experience and appreciate the value of bringing together local and scientific knowledge. It was noted by one interviewee, that they wished to operate in this way, but often experienced resistance from the management level, as well as from other colleagues. The smaller OROs had the commonality of having a relatively large amount of influence over their approach. They are governed by Trustees and often secure grant funding, which, on the whole, affords them more flexibility over the whole project design. In addition to this, these groups are extremely resource limited and must prove that they are making the most of the funds granted to them and that the work they are doing has multiple benefits. Through this, I believe they have come to use experiential knowledge as a *resource* with numerous benefits. Firstly, it can be used to provide information about an area that simply cannot be gained from short term monitoring (grant funding is often for fixed, short-term periods). Secondly, by involving the public, local experts and stakeholders, river managers demonstrate that they value local knowledge and input. This is likely to develop trust between local participants and the river management organisations (Henriksen *et al.*, 2009), encourage local experts/the public to be more cooperative, more understanding of different viewpoints and more willing to be involved. While this works well for reach-scale projects which are often focused around a community or group with a common

interest or cause, it is seldom practical or even possible at the catchment scale where numbers increase and agendas diversify.

While the sample size used here is a relatively small proportion of all of the flood-risk projects underway in north-west Europe, and the findings cannot be considered conclusive for the whole river management community, the results highlight some interesting relationships for those groups investigated and point to the issues that may be encountered by other river managers.

4.4 Linking practical cases of participatory research to theories of knowledge production

By comparing the findings with the models presented by Callon (1999), it can be understood why such approaches and difficulties in progressing to high degrees of participation exist for river managers at a number of scales. Most projects showed some attempt to achieve Callon's 'Co-production of Knowledge' model (CKM) at some stage. However, the majority of activities described fit most closely with the 'Public Debate Model' (PDM), in which the public and local experts are given the opportunity to comment, but decisions remain in the hands of the governing body. For the CKM (Figure 4.1c) to be successful, there needs to be a process of *constant and close collaboration* (Callon, 1999, 90), in all directions, between scientists, intermediaries and local experts. For projects operating above the reach scale, this amount of interaction is impractical and often entirely unfeasible due simply to the number of people involved. Callon's (1999) models suggest three distinct and progressive approaches to participation. However, in reality, degrees of involvement vary across a spectrum, perhaps more appropriately described in models such as Pretty *et al.*'s (1995) 'Typology of Participation' because in any one project, different degrees of participation may be appropriate at different stages (Kindon *et al.*, 2007).

Callon's CKM model describes an ideal in which there is the optimum number of participants in each category (e.g. scientists, intermediaries, local experts) in order to create an arena for effective exchange. However, as project scale increases, the number of local experts becomes disproportionate to the number of scientists and intermediaries, to the point where personal exchange of knowledge becomes unfeasible. Furthermore, the three different groups of participants within the CKM (scientists, intermediaries and concerned groups) are over-simplified and not reflective of the complexity of real-world situations, when considering catchment scale projects. The very nature of river management means it involves and affects many people, in

different ways. Indeed, many of the interviewees involved in this research suggested they could not assign themselves to one of Callon's models because a) situations changed over time (appropriate participation types are applicable at different stages within a project or arise from different contexts (Kindon *et al.*, 2007, 16)); and b) the response would be dependent upon how the terms 'concerned group', 'scientist' and 'intermediary' are defined. One respondent noted that the 'scientists' and 'intermediaries', in the context of small, charity groups, are often the same people and it is in the very act of combining these two roles that true interaction with the 'public' takes place. Although the CKM appears to recognise this, and address the issue by referring to one wider research group in which all members have influence, this can only be realistically implemented when group numbers are small. In the current study, it was reported that there are many participants who may be considered a 'concerned party', some of whom are heavily involved in providing knowledge (i.e. local experts, which may include farmers, landowners, anglers) and some who are interested, but do not contribute expertise. Whether an approach can be considered as one which uses co-produced knowledge is dependent upon the interpretation of the term and is demonstrative of Jasanoff's (2004b) proposal that the definition of a 'citizen' (or 'concerned party', in this study) affects the outcome.

It is proposed, therefore, that while Callon's models are an effective theoretical summary of the possible approaches to participation, in order for them to be applied to real-world situations (and specifically those in the catchment-scale river management context) they must be deconstructed and more specifically defined (see Figure 4.2). Callon comments that "...there is no reason for one model definitively to replace another...the organisation and production of knowledge on problems concerning the environment...could easily fit into Models 2 and 3 [PDM and CKM]and the hybrid forums they organise." (Callon 1999, 93-94).

It is suggested that a more practical aim for river managers is one which primarily incorporates both the differentiation of publics found in PDM and the mutual knowledge production with *some* concerned individuals (those most affected) of CKM, but which also reaches out to those on the margins of the field. Figure 4.2 outlines a suggestion for a more reflexive approach to participation based partly on the successes (and problems) identified in this study. In this new model, 'non-experts' are not confined to a single classification, but can be made up of a number of groups with varying levels of interest or stake in a project. The degree to which a member of the public is involved in knowledge production is dependent upon how interested they are, the level of experience they have to inform the knowledge they provide, and the degree to which they may be affected by management practices or changes. In this case, river managers (whether

they be scientists, statutory authorities, funders or charities), work together, directly, with the local experts to determine appropriate research questions and focus research agendas so that they are based around the issues that have the greatest level of importance, or the greatest impact, rather than those issues that researchers or managers are best equipped to deal with. Local knowledge is incorporated into the entire process so that it can help to inform every stage of research and decision-making, including the validation of initial research findings and redesign of approach, when necessary. When it is appropriate, other members of the public, such as those who may be affected by the outcomes, or those with a general interest (but with limited experiential knowledge) will be involved. The model describes an iterative and reflexive process which is designed to change to suit the case in question and to create a process in which feedback can be effectively incorporated. It is hoped that this approach would help to achieve the optimum level of involvement for every party. One limitation however, as with Callon's CKM, is that as scale increases, this model may become increasingly difficult to implement.

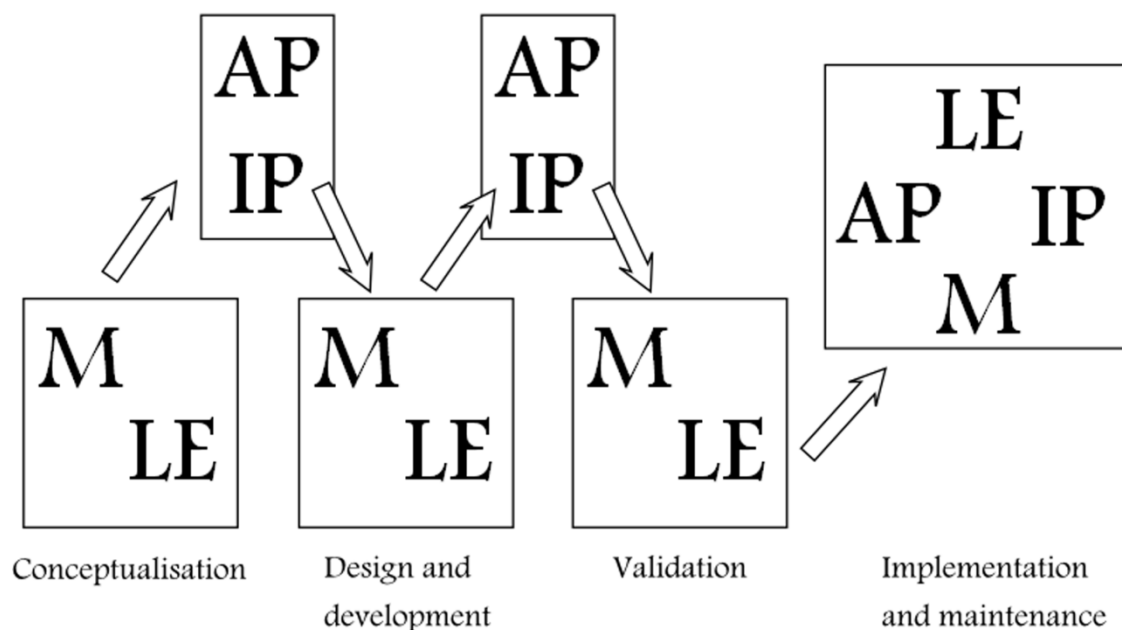


Figure 4.2 New model of participation proposed for use by catchment management organisations at different project stages. Where: M = Managers; LE = Local experts; AP = Affected public; I = Interested public

4.5 Conclusions from the Organisational Review and implications for the Ebchester Study

This research highlights difficulties experienced by large organisations when trying to achieve a high degree of participation in river management. Some believe they are affording local experts and the public as much influence as they deserve, while others see the process as a burden which is inhibitory to the 'true objectives' of environmental management efforts. However, most interviewees suggested that although they appreciate the value of developing new understandings in collaboration with local experts, the remit of their position and size of their projects simply do not allow it. Those working at more manageable scales but with limited resources appear to have developed an attitude towards participation which is beneficial not only to the environmental outcomes, but to all participants involved and their organisation as a whole. Recognising the role of certain individuals and fully opening up the knowledge production process may serve to alleviate reservations experienced by some of the parties in this investigation regarding the wide-spread practice of participation in which local experts are afforded a large amount of input. The findings here raise the question 'given the practical constraints placed on large river management organisations, who *should*, and who *can*, effectively practice high degrees of participation and co-production?' In the light of legal requirements such as those of the WFD, continued investigation into what degrees of participation are feasible, given institutional constraints, is essential.

This chapter has presented and discussed the approach of a number of river management organisations to participation, and their relative successes. It has also considered the major constraint (scale) experienced by many organisations, which limits their ability or desire to practice participation. The costs and benefits of the use of local knowledge in practical river management projects have been evaluated, and the use of participation as a resource by some smaller groups has been proposed. In the next section, a different study will be introduced, in which the merits of local knowledge are considered when the constraints of scale, funding, and managerial remit are removed. A small competence group, who have an interest in the state of a degrading weir on a river local to them, are gathered to design and implement a research project into the impacts of restoring the weir. The results will ultimately be discussed in relation to the findings of this chapter and the importance of constraints such as project scale, management limitations, and pre-determined requirements will be considered in the contexts of both large scale, intensely managed organisations and small scale organisations which build their success upon the relationship they develop with scientists, communities and local experts.

Part III:

Interdisciplinary, participatory
research case study

Chapter Five

The Ebchester Study: Context and process

5.1 Introduction

The benefits of participation in river management, and the role of a higher level of involvement, including knowledge production, were outlined in Chapter Two. Chapter Four outlined the approach and results of a strategic investigation of the approach that a number of river management organisations (specifically referred to as OROs) currently take to participation. The findings of that investigation highlighted a number of issues encountered by a number of the OROs when attempting to carry out participation in river management. These included the appropriate level of involvement for participants, the difficulty in achieving co-produced knowledge, and the important role of scale in practising high-level participation. In the second stage of this thesis, a participatory approach was used to address these issues in a separate, empirical project, in which a group of concerned residents were able to explore and analyse the impacts of a changing river environment on the river reach in their village. The group consisted of a number of local residents, and myself, the external researcher. Knowledge shared within the group was provided by the residents, myself and sometimes, from external sources (e.g. planning advice from the Durham County Council or the Environment Agency).

This chapter aims to frame the participatory study by offering an overview of the various knowledge types relevant to the case study. These include experiential and scientific knowledges. Experiential knowledge covers aspects of the use and behaviour of the river, the reach local to Ebchester, the weir and the history of these aspects. The scientific knowledge includes specific catchment and reach details of the physical and environmental nature of the river (required for a research approach such as modelling, which is adopted to contribute to the further investigation of the EWRG objectives). This type of information provides data about hydrological,

geomorphological and ecological aspects of the catchment, as well as industrial background. Further to this, the scientific knowledge includes a general understanding of the processes within a river system and the expected response to changes such as weir restoration. These process understandings are later framed and contextualised for the reach in question, through scrutiny by the group as a whole.

In order to present the knowledge shared among group members, and to frame the rest of the participatory process in this study, the current understandings of the river and reach are presented in this chapter, in three sections: i) the local, experiential knowledge used to establish research objectives, and which questions results later in the thesis (Section 5.2); ii) the scientific knowledge of the catchment and the reach (primarily in the form of primary data) (Section 5.3), and iii) the 'scientific' process understandings which are used to provide a basis from which to discuss model results later in the thesis (Section 5.4). The chapter concludes with a summary of the knowledges presented, and a reiteration of the EWRG objectives.

5.2 Experiential knowledge: knowledge shared through the competence group meetings

5.2.1 Composition and purpose of the Ebchester Weir Research Group

As detailed in Chapter Three, the competence group that was assembled in this project was done so through communication with the Tyne Rivers Trust, and communication at a publicised drop-in event for the residents of the Derwent catchment (see Section 3.4.3). Communication with the Ebchester Weir Restoration Group (EWRG, see Table 3.3 for a list of members and their contribution to the group), in its various forms, from Competence Group Meeting 1 to Competence Group Meeting 3 (see Section 3.4 for outline of participatory approaches) allowed the EWRG and myself to share a great deal of information concerning the river at Ebchester and how it behaves now, how it has behaved historically, and the societal value of the river system. In addition, we pooled knowledge on external controlling factors to management and restoration, including legislation, legal requirements for management, ownership and local disputes. Along with all of these themes, which will be discussed in turn below, we identified the individual and group concerns about the river, the state of the weir, and the potential restoration, as well as some suggestions for management approaches. The process led to the establishment of a number of research objectives for the EWRG, and these will be presented at the end of this section. First, the concerns and interests of the group will be discussed.

5.2.2 Aims, concerns and interests of the Ebchester Weir Research Group

The remit at the outset of the project was

“to restore the weir so that the area could be used for boating and to maintain important ecosystems. It would also be part of a wider move to improve the ecology of the area” (M1, initial meeting before CG1).

As the communication and the EWRG grew, the concerns and interests of the group expanded and became more specific to certain aspects of physical and social processes. The concerns raised were related both to the specific topic of this project, and also to the weir and the river reach more generally. These can be categorised into a number of sub-themes which include: impact of a restored weir on water level; the implications of fish passes and other structures; impacts on sediment dynamics and vegetation under a restored weir; manual vegetation removal; social implications and ecological implications.

5.2.2.1 The impact of weir restoration on water level

The main concerns for some (M9 and M10) were based around the impact of a new weir on water level. This was especially significant for two members of the group who lived very close to the river, and on the floodplain (the majority of the village is located at the top of a steep valley). Their concerns were with the increased likelihood of flooding if the water level behind the weir was to be elevated, and whether a restored weir would cause increased rates of erosion to the banks closest to their homes. It was pointed out (by M5) that if the restoration resulted in an increase in water level of 6-8 inches, this height is often reached in flood events already, but M9 suggested that if the average flow height increased by 6-8 inches, the water level in flood may be much higher. The two members concerned (M9 and M10) repeatedly referred to the large flood event which occurred in September 2008 and used this as a basis for all of their questions and speculations (this event had a return period of 56 years, or a 1.8%/0.018 probability of occurring in a given year, although this figure may be limited by the number of years of flow data as the flood event was the largest on record by a significant margin).

The impact of a restored weir on water level was also of interest for more positive reasons in that it would increase the capacity of the pool behind the weir for activities such as rowing (this is discussed in the ‘social implications’ section (5.2.2.4) and ‘Social aspects of the river’ (Section 5.2.5)).

5.2.2.2 Implications of fish passes and other structures

The potential requirement of a fish pass was discussed at length in CG1, and at CG2 it was confirmed that by law, if the weir was to be repaired, some form of fish easement must be

provided. One of the major group concerns associated with this was the implication for the water level. For many members of the group, raising the water level behind the weir (whether this be for aesthetic, leisure, or ecological reasons), was the main priority. When a fish pass is installed, it requires a minimum flow rate in order to generate a velocity suitable for the fish to use the pass (this is variable according to the river and the nature of the pass: Jormola, 2012). This means that water may need to be 'directed' towards the pass, and that the overall increase in water level behind the weir could be negligible. Fish pass construction is a very expensive process and the members of the group began to question whether the requirement of the pass would negate the restoration effort, as summarised by one group member (M2) in CG1:

"...because if they're 'fixing' the weir, but then a flow is required around one side of the weir [for the fish pass], that's going to have implications to how it is done but also ultimate levels, which is what you're [speaking to M5] looking at in terms of being able to use the pool upstream."

Furthermore, as a secondary issue, the potential for the generation of hydropower was considered, possibly as a means of generating funds to support related maintenance and development work around the weir. While all group members agreed that the initial repair of the weir was their main priority, hydropower received much attention in discussions. The potential location of a hydro system was discussed and it is likely that this would be at the opposite end of the weir to the fish pass (i.e. the end near the boathouse, see Figure 5.2). The question was raised over how much water would be required to sustain *both* the fish pass and a hydropower scheme, and whether aiming for this would be worthwhile, bearing in mind the requirement for an increase in overall water level behind the weir. The fish pass would be prioritised in low flows, and the value of the amount of energy generated with the remaining water available was questioned:

"Am I right in saying that there would need to be a significant demand to power the turbine and divert water for a fish pass as well?" (M9, CG1).

At this point, the role of the 'scientific approach' was referred to by one of the group members:

"Well I'm just gonna say....that's where you [me, the researcher] come in! As in the modelling side." (M1, CG1)

It was suggested that the modelling approach could be used to determine how the water level behind the weir would respond to a number of scenarios, including the restoration of the weir and a hypothetical, degraded weir.

5.2.2.3 Impacts on sediment dynamics and vegetation under a restored weir and 'local management initiatives'

Questions were raised (primarily from an ecological point of view), over the impacts of a restored weir on sediment dynamics and vegetation cover both upstream and downstream of the weir. The implications of the concentration of flow in one or two locations downstream of the weir, on sediment transport (and therefore habitat) was questioned. In addition, the level of fine sediment deposition upstream of the weir was discussed. This is an issue for a number of group members because, in conjunction with water level, it affects the usability of the pool for boating. Diverting water to a fish pass and/or hydro scheme was considered a risk because it would reduce velocity elsewhere in the cross section and lead to increased sediment deposition in these areas.

The group also had an interest in the level of vegetation on the bar downstream of the weir. It was theorised that this vegetation slows flow and, should it be removed, the likelihood of flooding would be reduced. Many of the group members were keen to voluntarily remove this vegetation and wished to know how this would affect flow rate, water level and flood incidence.

5.2.2.4 Social implications

For some of the members of the group, Ebchester has been their home for their entire lives and many have nostalgic interpretations of the area. To restore the river to the state it was many years ago, when it was a social hub which supported many recreational activities, including a boat regatta, was a desire for many. To reinstate what was once a community resource was a priority, as described by M5 (CG1):

"I had a wonderful childhood by the water and on the water and would like to see that happen again for kids in the village....My aim is just maintaining the status quo so that something which has been a resource for the village hasn't been completely lost."

And another describes their priorities as

"In terms of objectives, [I would like] the diversity and the aesthetic value [to] be there, and get the water level back to where it was with the crest of the weir, from a boating point of view, but also to keep, to maintain the depth of the water" (M3, CG1)

5.2.2.5 Ecological requirements for the river

To build on the recent improvement to fisheries in the river, some group members expressed a wish to see an increase in natural fish recruitment and sustainable fisheries. This would be assisted by the installation of the fish pass, allowing anadromous species such as Atlantic salmon,

to use the habitat within the river more extensively. The overall benefits of the weir restoration are summarised by M6 (CG1):

“I’m very keen to keep the structure of the weir, I can’t think of any reason at all why anybody would wish it to be removed – it’s historical position, its community value, you can tick all the boxes on it. But I would be keen to see some easement for fishes on it.”

The river is believed to accommodate a diverse range of species, and the environment (unusual to this area, provided by the slow flowing water, with a silty bed, in close proximity to fast flowing, gravel beds) will allow a more diverse range of fish and macroinvertebrate species to inhabit the area:

“...what goes on down there, is the provision of a habitat that’s quite different from anything else around. That, you know, that’s an increase in diversity. Okay, it happens to be man-made, but it doesn’t make it any less diverse as a result. And erm, to me, I just like looking at it and watching the creatures that come along there..... what I like is to be able to look down and see all these different kinds of birds around that wouldn’t be there if it weren’t for that weir, that long stretch of still water.” (M1, CG1)

5.2.3 Historical characteristics of the River Derwent and changes over the last century

One of the strengths of local knowledge is that of information held by those who experience a river during the course of their lives, which leads to an understanding of how the river has responded, in the long-term, to changes such as impoundment, or climatic changes. This knowledge was abundant within the group and is discussed below, according to two main themes: history of the weir, and impacts of river impoundment for Derwent Reservoir.

5.2.3.1 General history of the weir and area

From general local knowledge within the community, a number of the very local group members were in agreement that the weir dates from the 17th century and was built to divert water down a mill race for a number of mills. The flow then re-joined the river roughly 1km downstream. In the last 100 years, there have been small degradations to the weir and M5 reports that there was some damage from 1975 onwards, with a flood event in 1984 causing significant damage to the structure and in the 2008 flood, large stone blocks were removed from the weakened points. M7 also estimated that gabions added to the top of the weir, on the right river bank, were installed by the council in the late 1960s or early 1970s. He/she notes that the gabions were to raise the water level to repair some damage to the weir near the point that flow would have been off-fed for the mills. M5 also comments on the recent establishment of vegetation. In the years when

the boat regatta was run (c. 1900 to the final one in 1975), the steep valley sides were cleared by the rowing club for use at the regattas, and also for timber. The valley side is now densely vegetated with mature trees and shrubs. The vegetation along a long stretch of the river upstream of the weir has changed:

“You can’t actually see what you used to be able to see from the near environs of the rowing club upriver. You used to be able to watch the whole course of the race” (M5, CG1)

5.2.3.2 Impacts of channel impoundment (1966 to present)

The group is in agreement that the greatest impact on the river has been the closing of Derwent Reservoir (1966):

“...the greatest impact that’s been effected in the river...by far the greatest impact on the ecology [and the] look of the river, is when the reservoir was built. We don’t have any winter flooding anymore. As a child I remember vast areas of the river being like they were after that flood [2008] virtually all year, and you would get quite a bit of green foliage came up in the summer, all washed away in the winter. Most of the banks, right down through Blackhall Mill [c. 2km away] were rocky, stony, bouldery banks, bit like you would see on the Tees, or something like that upstream...” (M5, CG1)

There is general consensus among the group that before the reservoir was built, the river was characterised by spate flows, sparse vegetation (because regular high flows meant that higher succession vegetation was unable to establish) and coarse sediment. Observations have been reported of vegetation establishing within the last 15-20 years, accompanied by a decrease in flood occurrence:

“what I would call ‘recently established’ of the last 15 years, of the new channel, which is right in the centre, the vegetation has encroached because it hasn’t been removed....” (M6, CG1)

This was attributed, by the group, to the absence of flood events stripping out the vegetation (however, the effects of the reservoir have been present for nearly 50 years, so it is possible that there are other controls at play here, or as a result of the delay between reservoir installation and colonisation of the higher successive vegetation such as trees). In addition to the encroaching vegetation, the reservoir is believed to have caused a growth in the mid-channel bar at Ebchester:

“[the bar] has certainly built up, if you look at these photographs [see Figure 5.1], has certainly built up over the years” (M5, CG1)..... “And the vegetation...and the nature of itthere’s more trees now....” (M1, CG1)

The lack of flood events is also believed to have impacted on the ecology:

“We’ve gone primarily from....clear interspatial habitat, fast flowing rivers....and invertebrates associated with that, to what is now, quite a scenic, on this river, mayfly hatch, which are predominantly silt dwelling. It was never abundant on this river, but it has now become hugely abundant.” (M6, CG1)

Flooding incidences are reported to have lessened in recent years, and the resident living closest to the river channel (M9) reports that his property has not been flooded in 90 years (although the 2008 flood extent was very close to his property).

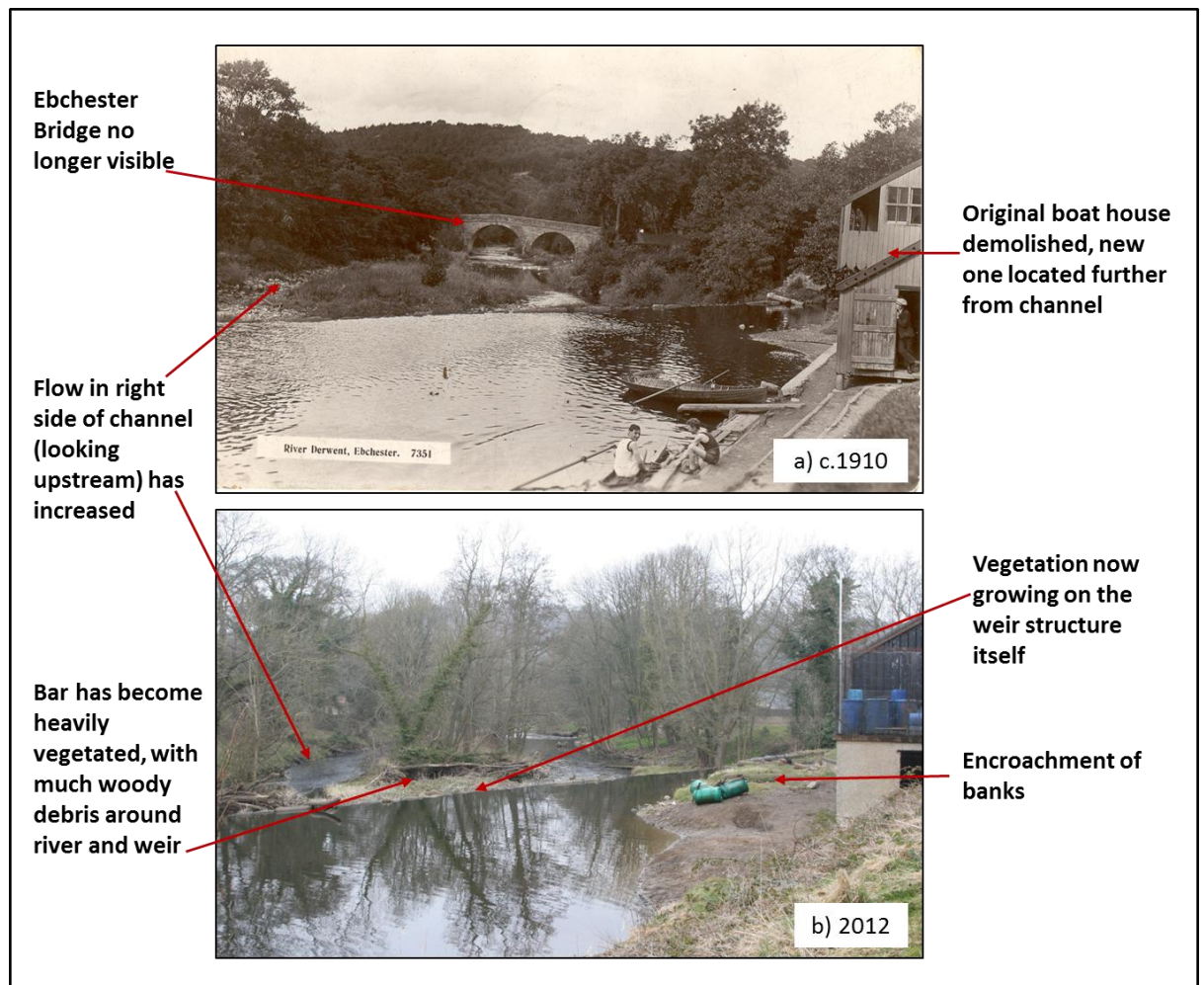


Figure 5.1 Photographs used to facilitate discussion on how river and surrounding area have changed over last 100 years, between circa 1910 (a) and 2012 (b). Photographs taken from same location on right river bank. Source (a): Dr. J. R. Hamilton; (b): Dr. C. Slater

5.2.4 Processes in the river and floodplain around Ebchester Weir

A wealth of knowledge was revealed through discussion with the EWRG. The information possessed by members of the group is of a nature which cannot be gathered by a single researcher over a period of two or three years, but is long-term, intuitive and experiential. In order to keep the discussion focused, only the information relevant to the objectives of the project will be covered here.

The weir structure has been deteriorating for a number of years, but one event (the severe flood in 2008) is believed by all group members to have significantly weakened the weir and removed a number of boulders from the structure.

5.2.4.1 Potential impacts of weir restoration

While one group member (M5) suggested that once the river had re-adjusted to a new, restored, weir shape, the same amount of water would flow over the weir and the overall impact would be negligible, another member (M6) pointed out that any increase in the height of the drop (hydraulic head) would increase the energy in the water and therefore affect scour rates at the base. Following this comment, M5 conceded and reflected upon evidence they had seen of this:

“That’s a point, and I think that’s certainly happened since that breach [since the weir was damaged in 2008], which is why my original concern came in, because I think because of that breach, I think the rest of the structure is probably in danger.” (M5, CG1)

M6 then notes that some aspects of the research can best be answered through scientific investigation:

“So, I think on that one, it would just have to be hard science that tells us what is going to happen there and that will have to be considered in the discussions. I don’t see it [restoration of the weir] being a huge problem downstream. I don’t think it will encourage downstream flooding but it might have an impact on the island and the gravel movements.” (M6, CG1)

Some of the discussion was centred around the effect of failing to restore the weir in any way. It was suggested that where the current weakness lies (see Figure 5.9), would be the point of further degradation:

“I mean, I would imagine if a breach occurred, where the worst hole is at the moment, you would lose all the flow just round that corner, all down your side [speaking to a resident, M7, who lives on the left side of the river], would rapidly become overgrown and you might even get, if the

breach was in that corner [left hand side looking downstream], erosion of [local farmer's] fields. If it was all, if all the fast flow came down there." (M5, CG1).

This was supported by M7, who noted that he had already observed degradation of this nature taking place in the location being discussed. The importance of ensuring that any new or restored structure would be 'tied into the bank' was discussed and it was decided that a failure to do this would enhance erosion into the adjacent farming field. Feeding into this topic was the recurring concern of the location of the proposed fish pass. The location suggested by the Environment Agency is at the same point that the current weakness in the structure lies, and where the group decided erosion could become an issue. Some members of the group strongly felt that the fish pass should not be located there:

"I would be concerned with an easement at that corner and what effect it would have on silting at this end [the end of the weir on the right, looking downstream]. If you were taking more of the summer flow down there [left hand side, looking downstream] and leaving this [right hand side looking downstream] dry" (M5, CG1)

Another member suggested that the proposed fish pass location would cause channel incision:

"You'd get a deep channel down that side [left side, looking downstream] of the river, right through the pool." (M9, CG1)

At CG2, the need for a fish pass to be on the most upstream point of the weir was discussed. This is because fish will swim as far upstream as possible before trying to tackle any obstacles. Therefore, if the pass was situated on a point of the weir that was further downstream, fish would become trapped at the most upstream location. This facilitated the discussion on where people would 'like' to have the pass so that it did not interfere with other uses of the river, and where the only effective location would be. Linked to this discussion, was the consideration of amateur repair of the weir, and a number of group members advised against this approach, suggesting that a significant flood may remove any amateur repairs and the issue would re-occur, only to need further attention.

5.2.4.2 Knowledge of channel flow and sediment

The amount of flow in the channel is understood in qualitative terms by a number of group members. One (M3) observes the low levels of flow experienced in the summer and suggests that flow is so low that to 'feed' a fish pass would account for all of the flow passing over the weir. It is also noted that this would cause a decrease in velocity at the opposite side of the river to the fish pass, and would result in increased sediment deposition. In support of this, M5 suggests that in

summer, flows would not be sufficient to both support the fish pass, and elevate the water level behind the weir, and that running a hydro scheme under low flows would be very unlikely:

“I think it could have possibly been feasible if we didn’t want a load of water going down the fish pass, but I think looking at it just as a cursory thing. I don’t think the river’s got enough water in it at summer level to....” (M5, CG1)

Following discussion based on access to the river (for data collection), the distribution of depths within the channel was qualified. M5 suggested that within the main pool behind the weir, there are a number of elevations and depressions, and that the depressions, known locally as ‘Summerson’s Hole’, can reach depths of 2.4m (or 8ft, as stated by M5), (see location on Figure 5.2). The increases in depth were attributed to the narrowing of the channel (and therefore greater proportion of flow over a certain area in times of flood, M5). Water depth in relation to rowing was discussed and it was pointed out by M4 that while the depth has been seen to be as low as 3-4 inches behind the weir, the pool is currently sufficiently deep enough for use of canoes, and that just behind the weir there is usually 2-3 feet of water.

Deposition of fine sediment is a major concern for the group. In CG3, it was noted that in the 2008 flood, most of the fine sediment on the bed was removed. Nevertheless, by 2011, there was a covering in places of up to 1 foot (0.3m) of fine sediment overlaying the gravel bed. This reduces available depth and also causes the water to become cloudy (turbid) when there has been heavy rain. It also encourages macrophyte growth within the channel, another obstacle to using the pool recreationally. It was discussed why the rate of sedimentation has increased in the last few decades. M5 believes it is a result of the reservoir and the lack of spate flows. I commented that a change in land use/erosion rates may also have an impact. As far as I am aware, there has been no change in release rate since the reservoir was built, but the members noted a marked increase in sedimentation rates in the last 10-20 years and particularly more recently than that.

Siltation is also believed (M1, M3, M4 and M5, in CG3) to have caused the river to narrow through the ‘growth’ of the banks over time. It was noted that siltation was causing the banks to grow into the river as they became vegetated and stabilised. There is an outcrop of land/sediment which today appears to be part of the floodplain. M5 explains that this was once a mobile part of the bed: a ‘spit’ that developed as a result of sedimentation from a small tributary which enters the stream just above the weir. This feature was regularly removed by the rowing club in the

past, but is now a stable, vegetated feature of the river bank. This point was used to illustrate the issue that the rowing club has with the rate of sedimentation in the area.

5.2.4.3 Knowledge of flooding issues

Local knowledge and historic photographs were used to examine the change in vegetation on the mid-channel bar (see Figure 5.1). M6 attributes recent flooding events to the recent establishment (over the last four decades or so) of vegetation on the large bar

“...the development of the vegetation on the berms [bar], that could probably cause the flooding because it’s that development that would change the water flows, the natural growth of trees will have a huge impact on the water flow – alongside and downstream – it will accelerate in some places and hold back in others.” (M6, CG1)

This point was developed through discussion and it was established that not only would vegetation increase the likelihood of flooding directly, but indirectly it can trap debris and further reduce channel capacity:

“Well then a lot of debris in the river will get caught in those trees and things and then that has a damming effect and pushes around, I mean you can see that.” (M1, CG1)

M10, who lives on the floodplain, reported that their property had not been flooded in 90 years (although the specific resident had only lived there for 27) and the group concluded that the large Derwent Reservoir (19 km upstream of Ebchester) must be having a ‘positive’ impact on flood events.

It has also been observed that flooding events can cause a flushing effect on fine sediment and this will impact the capacity of the pool and water depth.

5.2.4.4 Ecological understanding

The types of fish and macroinvertebrate species present in the river have been observed and include mayfly (which are associated with silted areas), and migratory fish, such as salmon and sea trout. Some were able to ascend a weir downstream and some were not. Access for migratory fish has been seen to improve since the weir was damaged in the 2008 flood and M6 used this fact to explain to the group the necessity for a fish pass, should the weir be restored. The importance of a weir restoration that supports the migration of some species was highlighted, and the subsequent impacts were explained by M6:

“if you get migratory fish back, and free movement of other fishes, including lampreys and eels, and the smaller less important fishes, bullheads, then we would be encouraging the river to go

back to its pre-industrial state in that sense, so the river will be better able to support a broader, diverse, biodiversity with otters, red kites...it's all interlinked." (M6, CG1)

The pool behind the weir is also known to support other ecological groups such as birds and therefore the group decided it was imperative that the weir is not allowed to deteriorate:

"...it certainly provides a habitat for water birds and things, having all that water there. I mean there are various sorts of ducks and things that come in, in the winter time" (M1, CG1), and:

"I think there are high levels of silt dwelling invertebrates in the area – it's part of a varied habitat" (M6, CG1)

Some of the main concerns and points of information have been displayed spatially in Figure 5.2.

5.2.5 The river as a social resource

The river system and the weir/pool area around Ebchester are not solely characterised by environmental features, but also have social value and meaning. This is demonstrated both through the positive social aspects that are associated with the weir, as well as those which cause concern, even opposition, to be voiced.

5.2.5.1 Positive social impacts of weir restoration

To many of the group members, the area around the weir in Ebchester, including the pool, the 'more natural' reach downstream, and the footpaths which allow access to a length of the river, are all seen as 'social resources' (M1). As mentioned above, the area and the features hold memories for many members of the group and of the wider community and to see the area restored to the vibrant social attraction that it once was, is a dominant reason for involvement in this project. The aim of raising the water level, for some, is primarily to re-instate the pool for regular boating use. A number of members feel the area is a resource for education, as well as recreation (M1), and an environment for community members to use and enjoy:

"it's clear that many people share that view [that the river is a place of beauty and houses a diversity of ecological species] because people love to go walking down there – ok they're taking their dogs out, but still I think people really like that." (M1, CG1)

Furthermore, the area is considered to be part of the culture, history and heritage of the village, and to many, this makes its social relevance as important as the environmental value it holds (e.g. M1, initial discussion meeting).

5.2.5.2 Opposition to the weir restoration and fish pass installation

A number of the group members have experienced some hostility from certain angling communities concerning the installation of a fish pass on the weir.

“...they would rather not have salmon, in what I would guess they view as a ‘trout and grayling river’” (M1, CG1).

One of the EWRG members (and also a member of the angling community) was able to help the group understand the concerns that had been raised. He explained that the arrival of migratory fish within the river is seen, by some anglers, as a threat to affordable angling:

“It is definitely a hot point for some of them, they think it will...landowners will say ‘wow we’ve got a salmon in, so we want ‘x’ number of thousand pounds now in rentals instead of a couple of hundred’” (M6, CG1)

Further concerns are linked to the ‘balance’ within the ecosystem of different types of fish species in which migratory species may compete with the extant populations. However, this particular angler suggests that the ‘natural balance’ should be allowed to take its course:

“The argument presented by some is the migratory fish will have an impact on the fishes, the populations of fish that are already there....and that may be, but it will be a natural balance, as and when it is balanced....and it’s far more natural to have migratory fish in than it is to have farmed fish in, for example.” (M6, CG1)

Opposition had also been experienced from other parties, for example, local landowners who felt that the changes may cause poachers to operate on the river. Within the EWRG itself, there were contrasting views around which river user should be prioritised:

“Well, yes, you know you keep seeing figures like a quarter of a million pound bandied around for putting the fish pass in, when, you know, you’re trying to like improve a place for some kids to enjoy themselves, you know, and it seems like the fish are coming before the kids.” (M5, CG1)

In addition, dispute arose over how funds should be allocated. Some members (e.g. M5, M7) thought of investment in consultancy as a waste (of time, as well as of money), while others (M1) show an appreciation of the weight that a consultant’s report can give to a proposition and yet others defended council groups who had made efforts to move projects forward (M6).

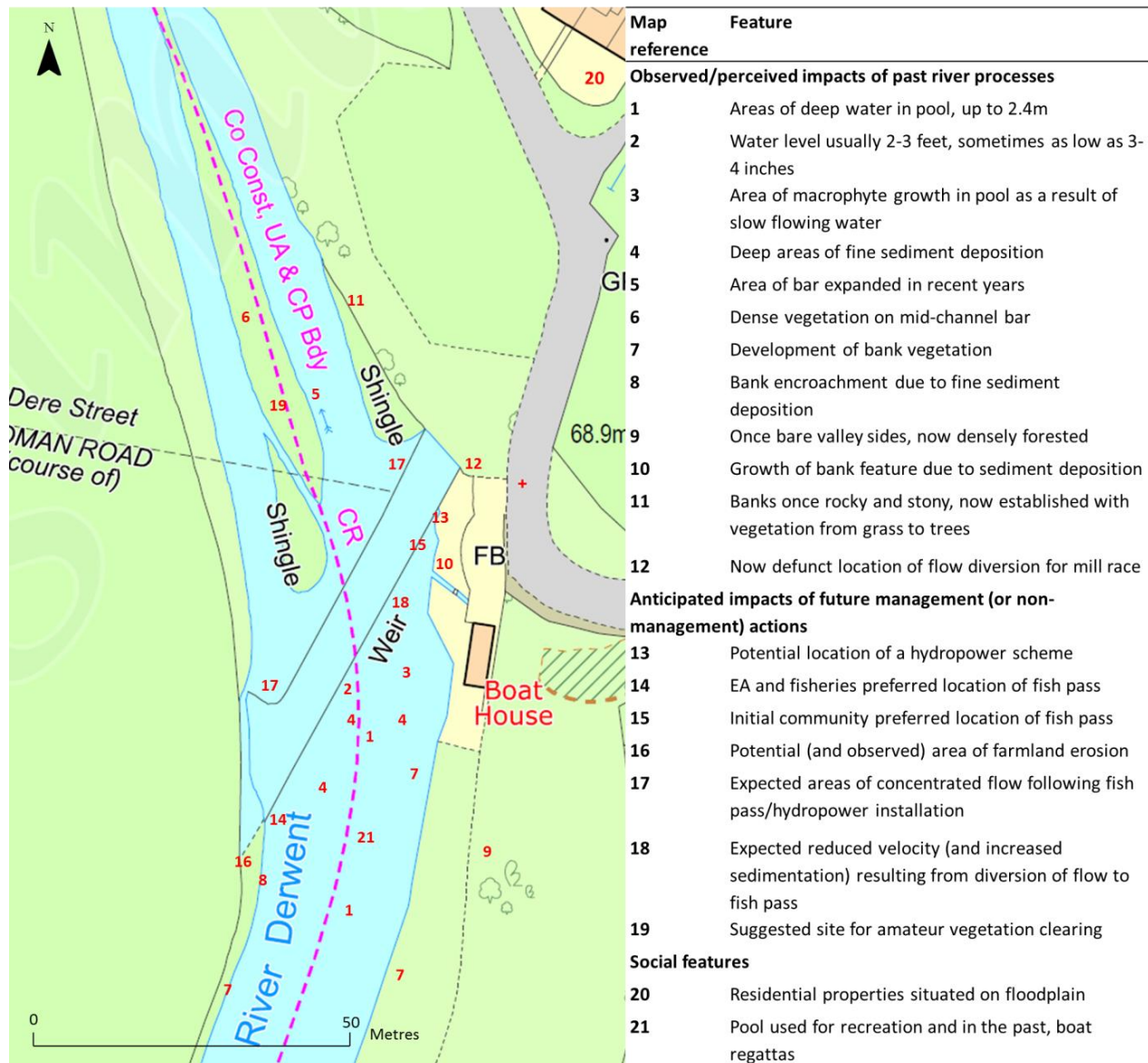


Figure 5.2 Geographical representation of knowledge and concerns based around the Ebchester weir. Issues are sorted according to topic and are listed in the adjoining table

5.2.6 External controls on management of the river and weir at Ebchester

The topics which led to the most unrest within the group were those which concerned legislative requirements, ownership, funding and the application of ‘amateur work’ (as termed by M5). There was initially a divide within the group, in which some believed that the legislation (e.g. for fish pass requirements) was too restrictive, unnecessary, and could be avoided by works being done privately by community members. Other members of the EWRG contributed information

which helped the group to understand why the legislative requirements were necessary. Sometimes an understanding was not reached, but those group members who wished to carry out amateur work were successfully dissuaded, even though they did not necessarily agree with the legal requirements. The main topics of dispute fell into two main categories: fish pass legislation, and ownership, responsibility and funding.

5.2.6.1 Legislation for the assistance of fish migration

A number of group members (M2, M6) pressed the point that any new obstruction to fish passage was legally required to incorporate some form of fish easement and this was not something that could be negotiated with the Environment Agency, or improvised upon. In an effort to explain why this was so, one member stated:

“...there has been easement since the September [2008] flood over that weir, for fish...And if you’re then going to repair the structure, and remove the easement, then there will be serious considerations. So I think the view that [M2] takes that if a structure is to be improved from [its present form] then serious consideration under, I think it is the Water Framework Directive.... And I think the EEC Directive, where it is established that there is ownership of an obstruction to fishes within the river, then it is the responsibility of the owner of that obstruction to ensure that fishes have easement over it.” (M6, CG1).

In CG2, the necessity to apply to the Environment Agency (EA) for permission to build a fish pass, and to do works on the river, was discussed. The group had asked a member of the EA for assistance with designing an appropriate fish pass, and the EA member had agreed to submit an application for works on their behalf. M6 also noted that if a fish pass was installed, ownership and responsibility for maintenance would need to be considered. This was a new obstacle for the EWRG and led to a discussion about the ownership of the weir and surrounding area.

5.2.6.2 Ownership, responsibility and funding

Ownership of the weir is disputed (M1, initial discussion meeting) and there was some discussion over the various owners in the meetings held. The weir and river lie on the County Durham/Northumberland border, meaning that the two county councils have overall responsibility for the land on the respective banks/floodplain. However, the land on the north bank is known to be owned or let by a local farmer and on the south bank, is owned by the National Trust. The boat house on the south bank of the river is also owned by the National Trust, which allows the Sea Scouts group to have a tenancy of the boat house, which, as noted by one EWRG member, has led to some conflict:

“They’ve [the Sea Scouts group] had the tenancy of the boat house but they’ve used that tenancy to stop other groups using the river, quite forcibly in the past and I think less, much less so now. I think they have realised the way the wind is blowing, but they have actively discouraged other users and I think to the detriment of the area – the children in the village and” (M5, CG1)

The uncertainty of ownership has hindered the project because it has led to problems both gaining permission to do the work, and in agreeing who should be responsible for the new structure (i.e. its integrity and its maintenance).

There has been much discussion over the issue of responsibility, with suggestions coming from within the group of the possibility of the community conducting repair and maintenance work (see also, Section 5.2.7). Some group members believe that this would help to avoid the legislative requirements placed on them by the Environment Agency and the County Council, but other group members warned caution should be taken. For example, one member (M1) noted that a sub-standard job carried out by the community could lead to future degradation of the weir, and even liability for its safety. Further to this point, M6 and M2 note that repairing the weir may be considered as illegal dumping, and the suggested clearing of colonised vegetation from the mid-channel bar would also be an issue for the EA (M2, CG3). In addition to regulatory constraints, M6 highlighted the process issues that could be associated with self-appointed river managers.

“...far too often people have enthusiastically done work on rivers and been very much unaware of the consequences of that work. For example, if you dig a hole in the river bed, it moves a river, they [‘non-qualified’ river managers] don’t understand that. If you weaken [geomorphological] structures upriver, it can cause changed velocities.” (M6, CG2)

Funding is also a topic of contention. M6 noted that Derwent Reservoir, which regulates the whole river, is managed by Northumbrian Water Limited. The group suggested that this company could contribute some funds to the work, as many believe that the reservoir is the source of a number of the problems (such as increased vegetation over the bar and weir, due to a lack of flood events). Durham County Council also expressed to the group some willingness to support the project in a financial and administrative capacity. The group were grateful for this, but were quick to assume that the Environment Agency would inhibit progress in some way:

“They [Durham County Council] had money that was leftover and they had to spend it on something and this is something they could spend it on. And I hope the Environment Agency doesn’t make that impossible... Yeah they [Durham County Council] had ... unspent money in the

pot and so this was a way for them to spend it and for us to get the funding and to get it done. But, you know, it's just a question of whether the Environment AgencyI thought they [EA] were almost sounding helpful, which was unusual, about trying to devise some scheme for fish easement or..."(M1, CG1 and CG2)

Throughout the process, there seems to be hostility towards the EA, as a regulatory group, many of the EWRG members appeared to believe the EA would block a project without due reason.

5.2.7 Group suggestions for river management approaches

The members of the EWRG were able to offer suggestions for various aspects of river management, based on some of the issues raised and the knowledge that was developed during the various meetings.

In order to alleviate concerns around the image of a fish pass, and the issues associated with erosion at the point of fish pass installation, a rock ramp was suggested by a number of group members (M2, M6). This approach has proven to be very effective for fish passage, while 'blending in' to the overall weir structure. However, these structures are very expensive to create and for a group with little or no funding, may not be an option. M6 also suggested that when legislation was not a constraint, there were some simple and inexpensive approaches to fish passage which would have minimal interference with the landscape in its current state.

There was some discussion around community-led initiatives such as vegetation clearing to open up the view of a downstream weir and to allow water to flow more quickly through the reach (during CG1 and CG3). There were also suggestions of amateur repairs to the weir and of clearing the channel of silt. While offered in good spirit, all of these approaches may be subject to legislative control in various forms, at least if advice was not sought prior to work commencing. One group member explained that this was to ensure that well-meaning community work does not inadvertently damage the ecosystem in question.

5.2.8 Synthesis of group knowledge and the way forward

Analysis of the value of the participatory approaches to knowledge exchange and development can be found later, in Chapter Nine. However, one main benefit will be noted here. The assemblage of a group of participants, each with experiential and valuable knowledge, can be a very effective means of identifying the concerns and issues of individuals, and of the group (McDonald *et al.*, 2004; Junker *et al.*, 2007). Some concerns can be allayed, simply through the exchange of knowledge within the group, others need more thorough investigation. The process of meetings such as focus groups and field site visits helps to determine which of the concerns

dominate within a group or community, and which can effectively be addressed through further study and knowledge generation (Junker *et al.*, 2007). In most cases, not all issues can be answered within the scope of one project (as was the case with the EWRG), but those questions/objectives which are most pertinent, and which may link up to address a bigger issue can be prioritised. This was done for the EWRG. The Preliminary research questions for the group were identified at the end of CG1. They were shared with the group and members were asked to comment on them. After discussions, and a chance to contemplate the new information provided in CG2 and CG3, the EWRG objectives which could be adequately addressed within the remit of this study were put forward and the group asked to confirm their agreement.

When deciding upon relevant questions to investigate, the capabilities of the 'scientific research(er)' must also be considered. It would be dishonest and counter-productive for the researcher to promise investigation of any and all questions proposed. Therefore, to manage expectations effectively (Hansen and Maenpaa, 2007 and see discussion in Chapter Two), a discussion with EWRG took place to establish how I was able to contribute. It was explained that in predictive analysis, numerical modelling is generally the best approach (Lane, 2003 and see Section 6.1) and that I was able to collect field data and prepare a hydraulic model to answer a number of the questions presented. If the model choice was made carefully, it would also allow me to use the model with the group and incorporate their feedback on preliminary results. It was agreed that this would be an appropriate approach and with this in mind, the research objectives for the group were finalised.

The EWRG research objectives are listed below, and those which were selected for the research process (based on a combination of importance, and research capacity), have been highlighted.

- 1. To determine the impact of a new weir form on the water level behind the weir and whether this would increase the capacity for using the pool for boating purposes**
- 2. Assess the impact of a new weir profile on sediment accumulation both upstream and downstream of the weir.** Would this affect the habitat conditions for fish and macroinvertebrates?
- 3. Investigate the implications of the proposed removal of dense vegetation from the mid-channel bar and consider how this would affect water conveyance through the reach**
4. To determine how much water will be required to maintain the fish pass, how this would affect the overall water level behind the weir, and whether it would leave potential for hydro-power?
5. Investigate the impacts of removing silt from behind the weir

The above sections have set out the experiential knowledge which is possessed within the group, and used to establish the research objectives for the participatory study. While establishing and prioritising research objectives, it was decided that a numerical modelling approach should be used to investigate the objectives and answer a number of questions proposed by the group. In order to apply a numerical model, and to understand the implications of the wider catchment characteristics on the Ebchester reach, an understanding of the hydrological, morphological and ecological features specific to this river is necessary. These are detailed in the following section.

5.3 Site of interest: Ebchester weir and the River Derwent

5.3.1 The Derwent Catchment

The study site chosen for this research is the River Derwent, a tributary of the Tyne in the north east of England (Figure 5.3). While the Derwent was chosen as the research river at the outset of the project, the specific location on the river was not chosen until after the drop-in session had taken place (see Section 3.4.2). This was to ensure that the project had the flexibility to focus on an area where a community of interested and knowledgeable participants could present a real and necessary research topic. This overview of the study site details, therefore, will be presented in two sections. The first will address the background characteristics of the River Derwent, which influence and shape the characteristics that would be found at any of the chosen study sites. The study site location that was finally selected (Ebchester), will then be discussed on a reach scale. Much of the study site description (at both scales) is based on primary data collected, and secondary data provided by the Environment Agency.

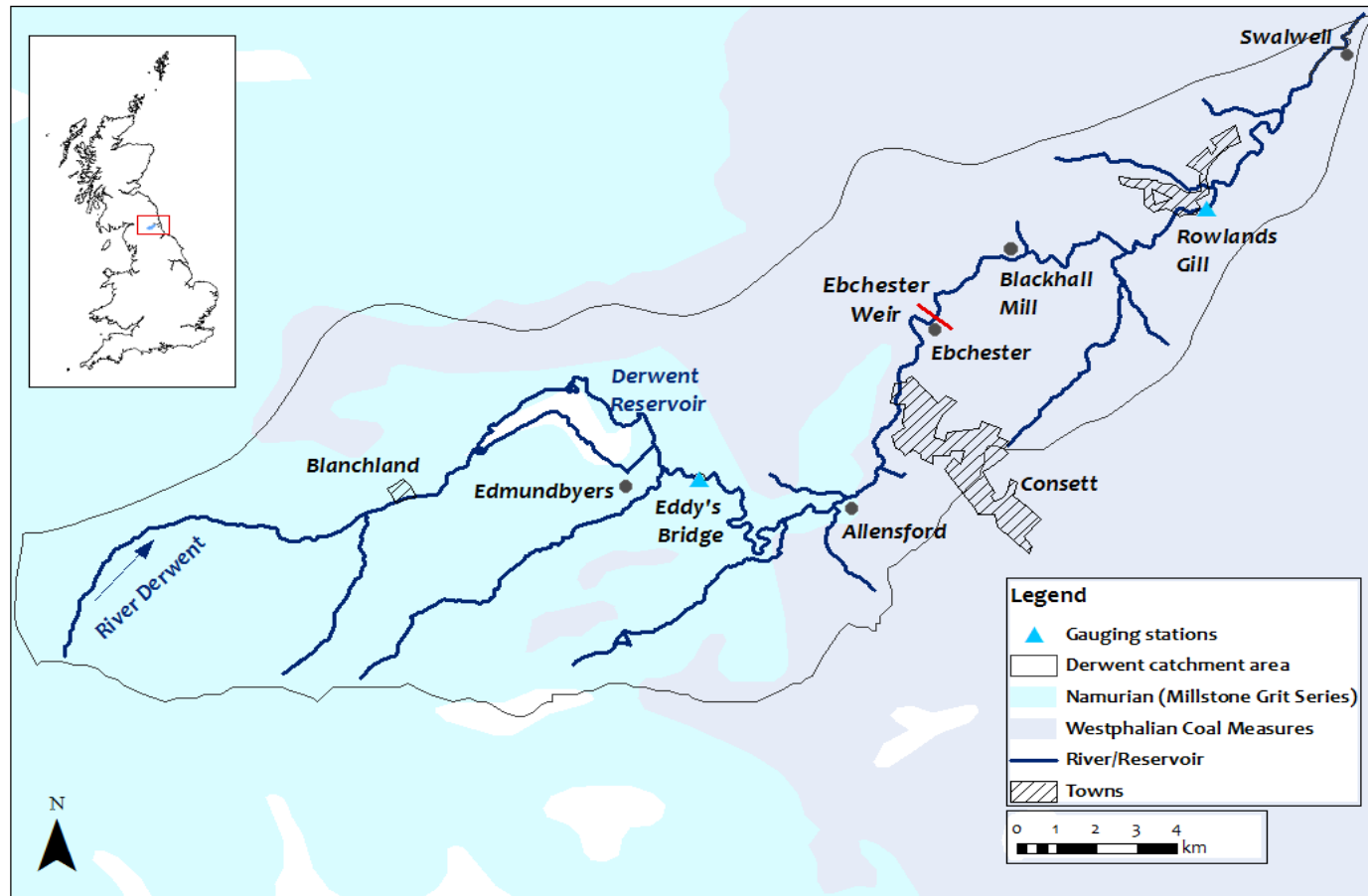


Figure 5.3 Study catchment: River Derwent bordering County Durham and Northumberland. The specific field site of Ebchester Weir is indicated by the red bar, roughly half way between the source of the river, and the confluence with the River Tyne

5.3.1.1 Hydrology of the River Derwent

The River Derwent, with a 266 km² catchment area, runs for c 50 km, from its source in the hills west of Blanchland, to its confluence with the River Tyne, at Swalwell. The catchment receives an annual average rainfall of 812 mm and has a low flow (Q95) at the downstream gauging point (Rowlands Gill), of 0.81m³s⁻¹. There are two gauging stations on the river; the most upstream at Eddy's Bridge (NZ410507) and the most downstream at Rowlands Gill (NZ168580) (see Figure 5.3). Gauged flow records available for analysis at Eddy's Bridge extend from 1954 to 2009 and at Rowlands Gill from 1962 to 2008. There is also a river level monitoring system at Blackhall Mill. All three are operated and maintained by the Environment Agency. The long term hydrographs for Eddy's Bridge and Rowlands Gill are displayed in Figure 5.4.

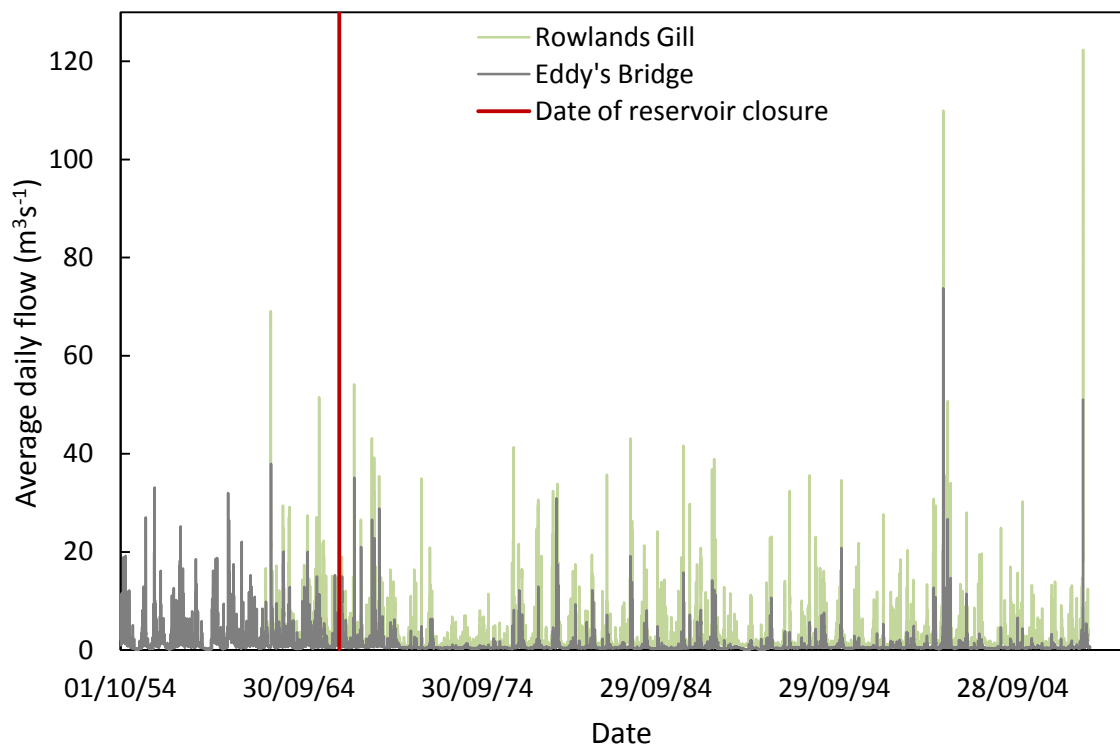


Figure 5.4 Long term hydrographs for the River Derwent at the upstream gauging site of Eddy's Bridge and downstream gauging site of Rowlands Gill. Data for Eddy's Bridge are available for the years 1954 to 2009, data for Rowlands Gill are available for the years 1962 to 2008

Since impoundment in 1966, the river has been regulated by releases from Derwent Reservoir, which lies between the small villages of Blanchland and Edmundbyers (see Figure 5.3), 14.5 km from the source of the river. The reservoir, which is dammed by a structure 1 km wide and 0.36km high, is 3.5km long, 4km wide, and has a capacity of 50,000,000m³. The area draining into the reservoir is 110km². The river downstream of the reservoir is regulated by compensation releases totalling 8,706,000m³ and distributed as 0.29m³s⁻¹ between April and September, and

0.26 m³s⁻¹ from October to March. There is an additional 827,000 m³ allocated for spate releases in any one year (Northumbrian Water Ltd., 2006). These spates may be used to flush the reservoir of fine sediment, relieve it of excess water, or provide freshet (short, fast flushing) flows to the river downstream. The reservoir is operated by Northumbria Water Ltd (NWL) and water from here is piped 3.5 km to the Mosswood water treatment plant, where it is treated and then piped to the town of Washington for distribution. The primary use is domestic supply.

Regulation of the river has resulted in a more stable, less flashy flow, with a higher baseflow index (0.63 compared to 0.43 prior to impoundment, see Table 5.1). Baseflow index, as developed by Gustard *et al.* (1992) for the Centre of Ecology and Hydrology, is the quantification of the proportion of river flow that is derived from stored sources (e.g. groundwater, lakes, reservoirs, etc.). Figure 5.4 shows the change in hydrograph shapes at Eddy's Bridge and Rowlands Gill following impoundment. It can be seen that low flows are higher and high flows are lower due to compensation releases. This is demonstrated in Figures 5.5 and 5.6, with the flow duration curves for Eddy's Bridge and Rowlands Gill before and after impoundment. Figure 5.5 shows that the flow duration curve for Eddy's Bridge becomes smoother and flatter post-impoundment, indicating less frequent low and high flows. At Rowlands Gill, high flows occur less frequently than they did pre-impoundment, but low flows appear to be lower and more frequent. These observations are supported by the catchment hydrology statistics summarised in Table 5.1 (calculated from EA long term hydrology data). The Richards-Baker flashiness indices (Baker *et al.*, 2004) calculated for the flow pre-and post-impoundment show that the flashy regime of the River Derwent at Eddy's Bridge was much reduced following impoundment (average flashiness index falls from 0.40 to 0.22, Table 5.1). At Rowlands Gill, the difference is much smaller. However, this may be a result of the small number of years contributing to the average for this site.

Statistic	Eddy's Bridge		Rowlands Gill	
	1954-1966 (Pre-impoundment)	1967-2008 (Post-impoundment)	1954-1966 (Pre-impoundment)	1967-2008 (Post-impoundment)
Q95	0.21	0.33	1.08	0.81
Q5	6.60	1.90	12.18	6.67
Q1	15.18	5.81	21.82	15.92
Median Q	1.01	0.45	2.83	1.43
Maximum Q	37.94	107.43	69.09	122.38
Minimum Q	0.11	0.08	0.62	0.28
Flashiness Index	0.40	0.22	0.3	0.28
Base Flow Index	0.43	0.63		

Table 5.1 Hydrology descriptive statistics for the River Derwent, pre- and post-impoundment.

Note: Q = flow rate (m^3s^{-1}), and Q_x = flow rate exceeded for x amount of time within the flow record. *Flashiness Index* is a measure of the frequency and rapidity of short term changes in flow (Baker *et al.*, 2004). *Base Flow Index* quantifies the proportion of river flow from stored sources (Gustard *et al.*, 1992). **Source: Maynard and Lane, 2012**

The impact of the reservoir on the flow regime of the River Derwent is most pronounced at the upstream site of Eddy's Bridge. This site lies only 1 km downstream of the impoundment. Rowlands Gill lies some 27 km from the impoundment and within this distance, a number of tributaries contribute unregulated flow to the hydrograph, reinstating much of the flow variability that is lost through impoundment.

Although the reservoir and compensation releases are able to provide more steady flows for the majority of the year, they cannot completely attenuate the effects of the most extreme flood events, which can be seen to occur at Eddy's Bridge in November 2000 and September 2008 in Figure 5.4. A limited proportion of the baseflow of the River Derwent is provided by groundwater, but where this does occur, connectivity between the aquifer and the river are good (EA Tyne CAMS, 2005).

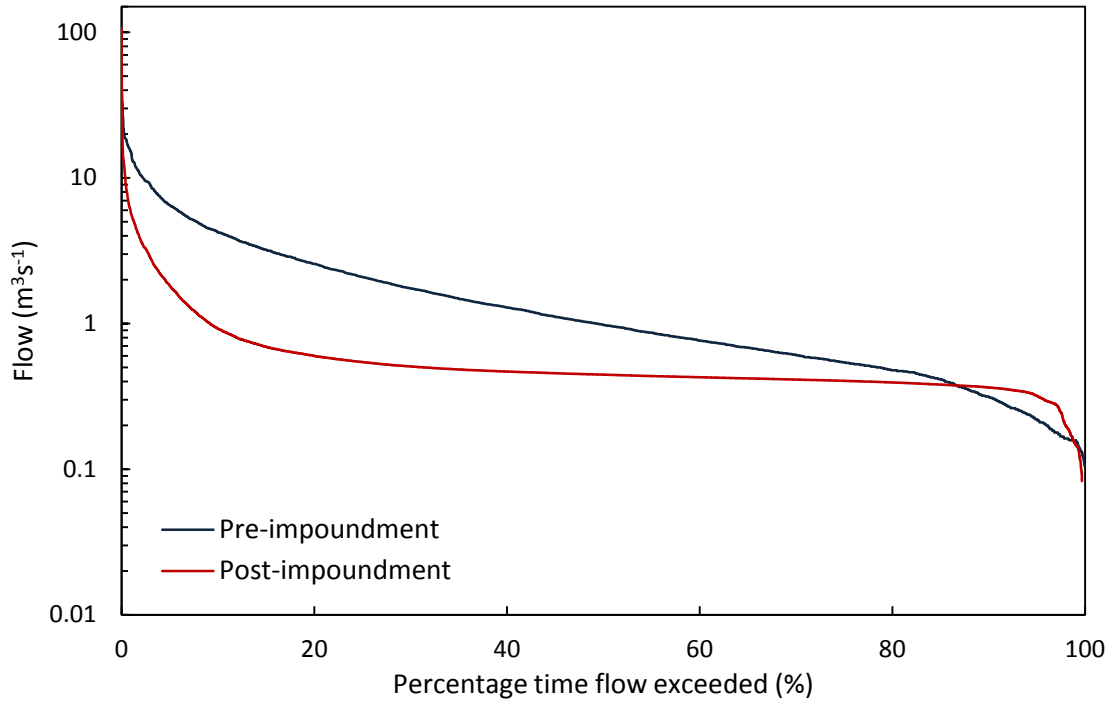


Figure 5.5 Flow duration curves for Eddy's Bridge, illustrating percentage time flows exceeded during pre- and post-impoundment periods. Calculations based on mean daily flow rates for 1954-1967 (pre-impoundment) and 1967-2009 (post-impoundment)

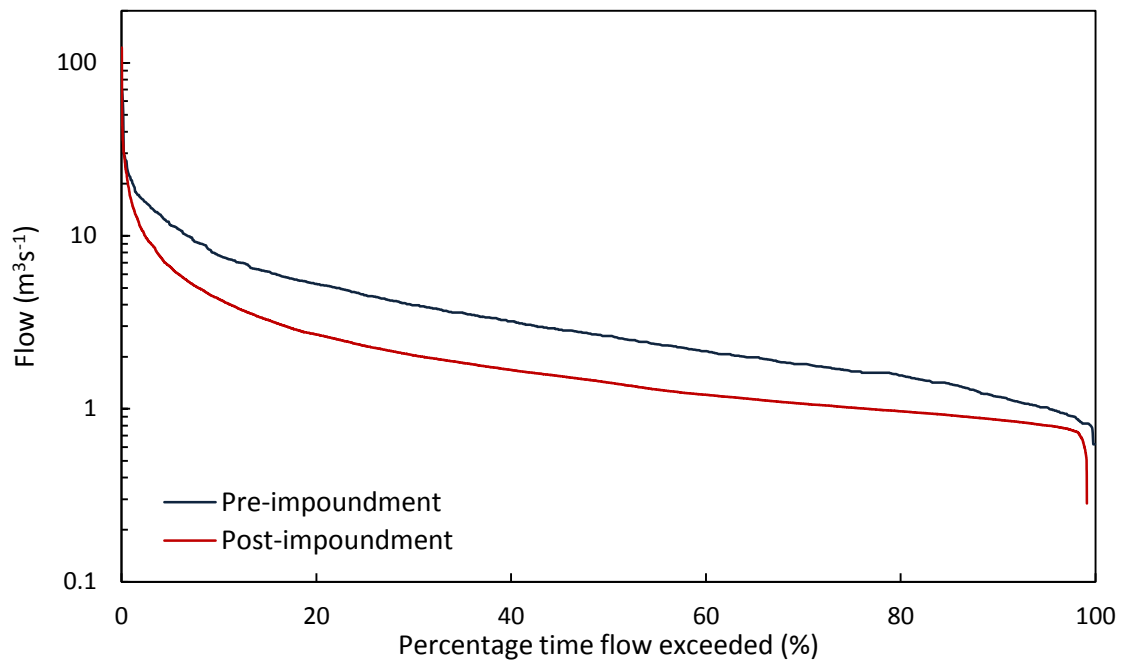


Figure 5.6 Flow duration curves for Rowlands Gill, illustrating percentage time flows exceeded during pre- and post-impoundment periods. Calculations based on mean daily flow rates for 1962-1967 (pre-impoundment) and 1967-2008 (post-impoundment)

5.3.1.2 Derwent catchment morphology

The geology of the Derwent catchment consists of two main categories. Upstream of Allensford, there is a Stainmore formation of Namurian age (Millstone Grit series) and downstream of Allensford the composition is mainly Westphalian coal measures (NERC geology maps, 2012), (Figure 5.3). Morphological form ranges from bedrock channel with almost vertical valley walls, to sand-bedded reaches with broad, flat floodplains. Between the reservoir and Allensford, the channel is tightly meandering, with a coarse gravel bed and pool-riffle sequences. Downstream of Allensford, meanders become wider and are spaced further apart. There is an increase in the number of gravel bars in the channel and at the banks and pool-riffle sequences remain common. This form dominates for most of the river length between Allensford and Rowlands Gill, however, in places, narrow bedrock reaches can be found with very steep valley sides and little sediment deposition. Towards the confluence with the River Tyne (Rowlands Gill and downstream), the channel becomes wider, straighter, with much finer sediment (predominantly sand, but with some gravel, cobbles, boulders in places) and with wider, flatter floodplains. The changing form of the river is illustrated in Figure 5.5.

For much of the length of the river, the valley is narrow, with confined, narrow floodplains. In these areas, and where bedrock dominates, lateral migration of the channel is limited. The reservoir has caused a sediment transport discontinuity within the river, but the effects of this are lessened because of the limited possibility for floodplain depositions. Although the floodplain levels out downstream of Blackhall Mill, narrow reaches with steep valley sides persist in places (e.g. near Chopwell Wood and Lintzford). Channel width ranges from around 5 m just downstream of the reservoir (Eddy's Bridge), to around 50 m at the confluence with the Tyne. However, within the middle reaches, there is limited variability around the mean of 17 m.

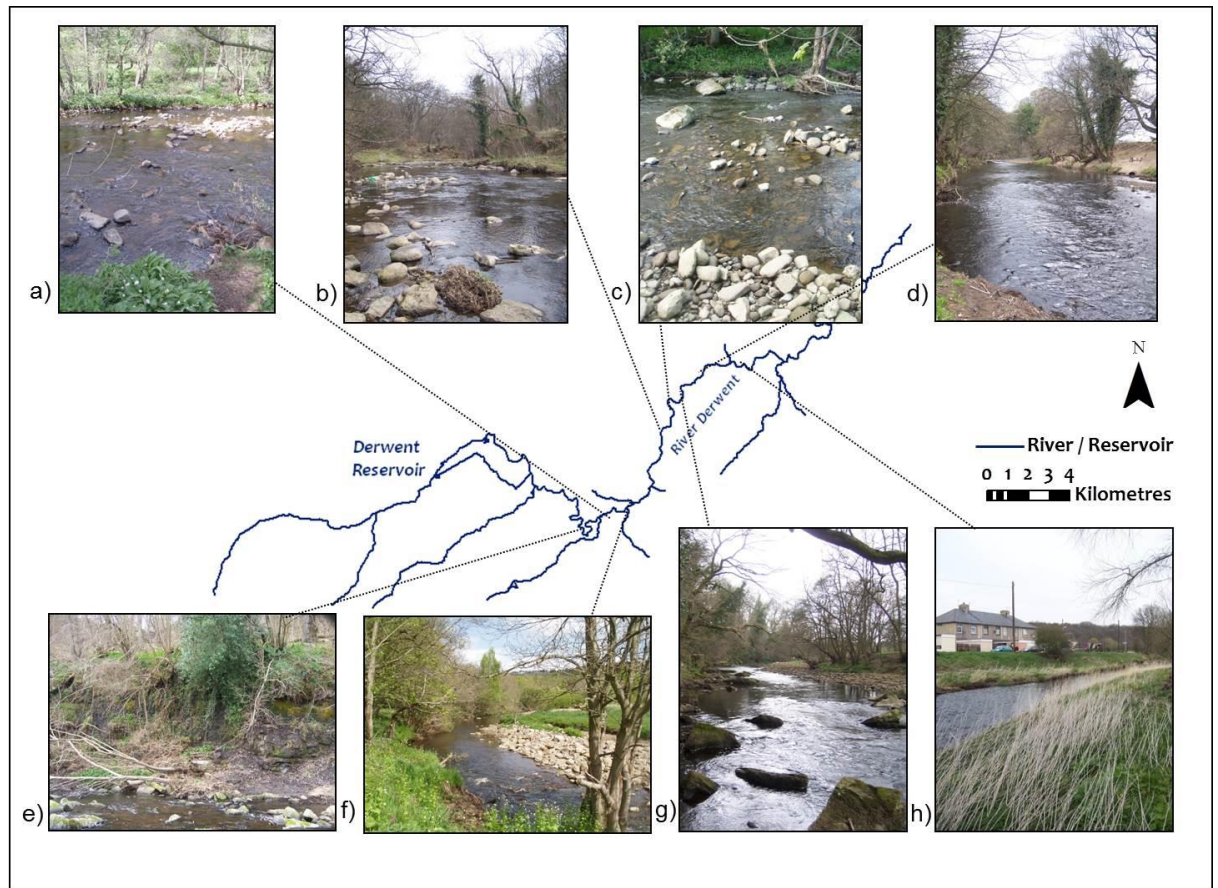


Figure 5.7 Morphological changes along the length of the River Derwent. Images taken at a) Allensford; b) Shotley Bridge; c) Derwentside Wood; d) Low Westwood; e) Muggleswick; f) Sodfine Wood; g) Ebchester and h) Blackhall Mill. Adapted from Maynard, 2010

5.3.1.3 Ecology and management of the River Derwent

The River Derwent supports a range of ecosystems and is home to a number of fish, macroinvertebrate and macrophyte species. Brown trout and grayling are currently found in the river and they return each year to spawn. Salmon and sea trout have trouble accessing much of the river due to a number of obstructions such as weirs (particularly at Derwent Haugh), they are not entirely absent however, and a small number have been anecdotally documented. The most common forms of macroinvertebrate include Baetidae, Heptageniidae, Ephemerellidae, Leuctridae, Elmidae, Hydropsychidae and Chironomidae (Maynard and Lane, 2012). A change in the composition of macroinvertebrate populations has been observed since the impoundment of the river. Richness and diversity scores have increased in some cases, and at worst, have not deteriorated. Maynard and Lane (2012) attribute this change in community composition to the increased stabilisation of flows since impoundment, although general improvements in the quality of all water courses, or changes in water temperature may also be influential. According to the Environment Agency's assessment of ecological quality, in 2005 the River Derwent, was

considered to be 'good' and 'very good' (EA Tyne CAMS, 2005). In the riparian zones, the majority of the river's length is dominated by dense vegetation on the floodplain, including established tree growth (Figure 5.7 a-g).

A number of environmental designations have been awarded to the river/catchment with an aim to develop or maintain the ecological value of the area, and include Special Protection Areas, Special areas of conservation, Sites of Special Scientific Interest, Sites of Nature Conservation Interest and Areas of Outstanding Natural Beauty. As well as environmental designations, the catchment has been the focus of a number of management policies or strategies, the most important of which include the Northumbrian River Basin Management Plan (2009, part of the WFD requirements), the Tyne Catchment Plan (2012) and the Northumbrian Water Ltd. Water Resources Plan (2009). Details of designations and management strategies for the Derwent catchment are provided in Appendices D and E.

5.3.1.4 Land use and industry around the Derwent

Land use within the catchment is primarily arable. Much of the area, particularly upstream of Allensford is dominated by grassland and moorland. There are also a number of wooded areas (some managed, e.g. Chopwell Wood, managed by the Forestry Commission, and those lining the river course at Ebchester, managed by the National Trust). There are a number of small urban areas in the catchment, the largest being Consett, lying to the south of the river. Current primary uses of the river and the reservoir are for recreation (including angling, and boating of various types), although the river was once heavily used as a resource for the operation of numerous mills along its length. One of the major industries in the catchment's history is Consett Iron works, which was responsible for some of the pollution of the river, but also for much of the ecological monitoring of the river's health.

Abstractions from the river are dominated by NWL, for domestic distribution, although there are a number of private abstraction licences for domestic and agricultural use. The water quality of the river, according to the Environment Agency's water quality assessment is 'good' (EA Tyne CAMS, 2005). Water quality in the Derwent is primarily affected by inputs from a number of sewage and water treatment works such as those at Mosswood, and there are some industrial inputs. The water quality of the River Derwent continues to be monitored by the Environment Agency. The Ecological Status, according to the Water Framework Directive classifications, for the Derwent, is 'Moderate', both presently, and potentially (Northumberland RBMP, 2009 Annexe A, p7). The river is currently failing to achieve good chemical status, according the WFD classification process (Northumberland RBMP, 2009, Annexe A, p10).

There are a number of conservation and monitoring efforts on the river, most notably those carried out by the Tyne Rivers Trust, including river watch and the Derwent Valley Landscape partnership projects as well as various volunteer operations.

5.3.2 The River Derwent at Ebchester

The reach scale site chosen to be the focus of this research project is the River Derwent at Ebchester, and, more specifically, the weir and its associated features. Ebchester weir is located 19 km downstream of Derwent Reservoir and approximately 36 km from the source of the Derwent (see Figure 5.8). The weir (Figure 5.9), approximately 400 years old, spans the width of the river (60m at that point), and is constructed primarily from large sandstone slabs. The roughly ogee shape rises vertically on the upstream side, while sloping into the channel at an angle of roughly 45 degrees on the downstream side. The presence of the weir has caused a back-up of slow flowing (almost slack in places) water, in a pool which reaches up to 2.5m in depth. The river channel widens significantly behind the weir as flow is slowed and obstructed. The slowing of water results in a loss of energy and, combined with the barrier to flow, causes high rates of fine sediment deposition in the upstream pool, reaching depths of up to 40 cm (which overlies a cobble, gravel and boulder layer on the bed). The upstream pool is 60 m wide just behind the weir and runs for about 125 m, tapering until the river narrows again to a width of 22 m. Vegetation on the banks is dense, consisting mainly of thick grass and shrubs, with some established trees. On the left bank, the floodplain is relatively flat for a distance of c.1 km, before rising to the sloping valley side. This area is primarily pastoral farmland with a number of small farm residences. On the right bank, the valley side rises steeply directly from the channel, with virtually no floodplain. This area is densely vegetated and the woodland here is managed and maintained by the National Trust. The majority of flow over the weir occurs in two places, primarily in the left side corner and also in the right side corner of the weir (see Figure 5.9). At these points, the elevation of the top of the weir has been lowered due to the displacement of a number of the rock slabs used to construct it. The blocky nature of the structure leaves it vulnerable to further degradation.

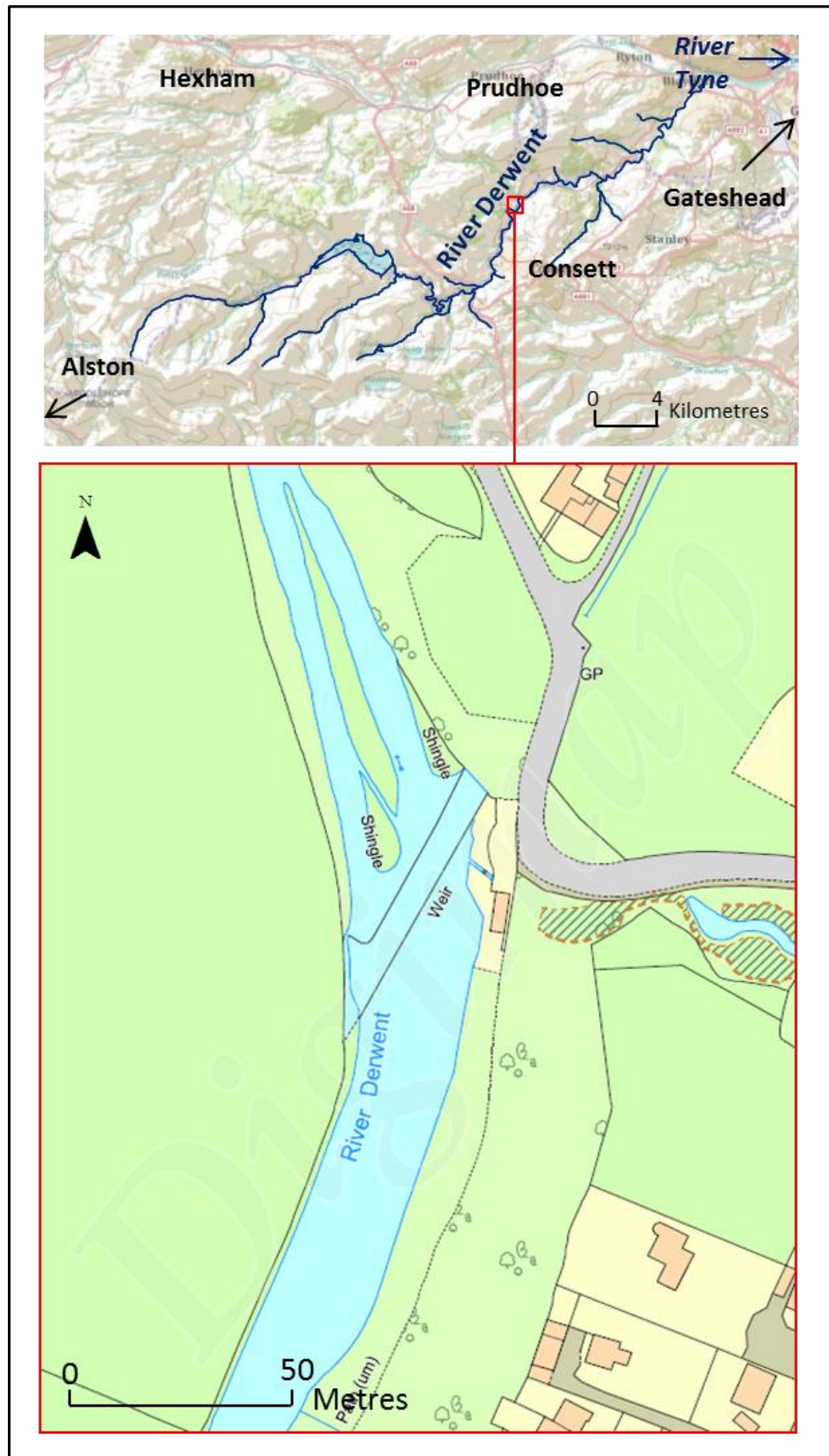


Figure 5.8 Location of Ebchester weir on River Derwent

Downstream of the weir, water is shallower, faster flowing, with a cobble/gravel bed and a number of pool-riffle sequences. Within the channel there are also a number of large boulders/concrete slabs which may have come from the deteriorated weir, or from old buildings on the site (a boathouse on the right bank has been demolished and rebuilt a number of times). The flow is divided by a large, well-established mid-channel bar, 100 m in length. The greater proportion of flow travels down the right side of the bar (looking downstream), where there are riffles and a number of deep pools. To the left of the bar, the channel is shallow, with fast flowing water and fairly even depth distribution throughout. The floodplain on the left bank is similar to that upstream of the weir, primarily grass and farmland. On the right bank, the floodplain is much flatter than it is upstream of the weir, after a small rise from the river channel of roughly 1 m. The flat floodplain is partially grassed, with a road running through and three residential buildings. This has a width of 50-60 m, before the steep valley sides rise approximately 20 m to the main village of Ebchester. The mid-channel bar is formed primarily from coarse sediment depositions and is stabilised with dense shrub, grass and tree vegetation (Figure 5.9). The bar rises from 0 m at the upstream and downstream ends, to almost 2 m in the centre, and spans 9 m at its widest point. The weir and channel features can be seen in Figure 5.9.

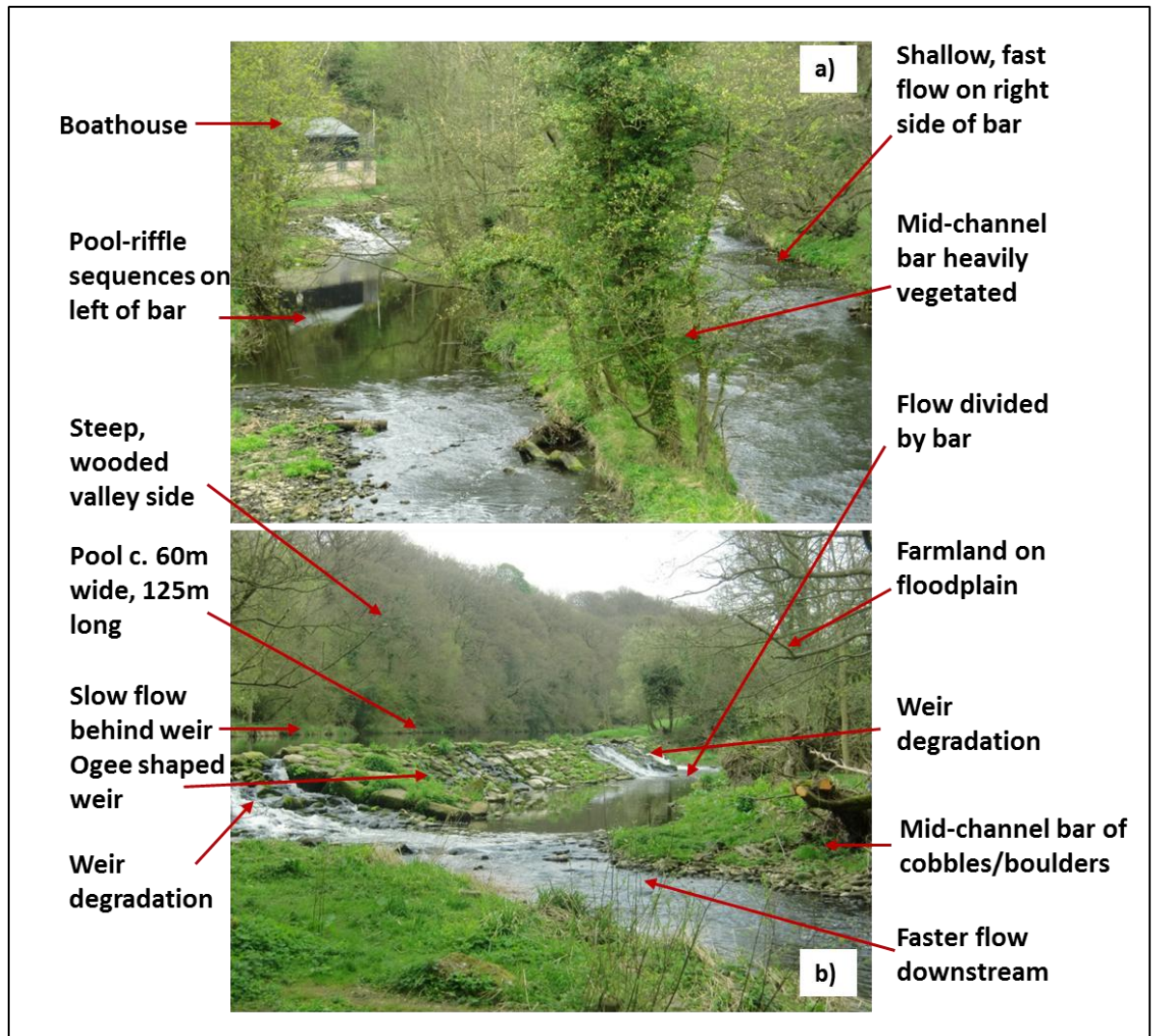


Figure 5.9 Physical and anthropogenic features at the study site of Ebchester: a) view from Ebchester Bridge upstream, past the large mid-channel bar, towards the weir (weir is located in front of boathouse on image); b) view upstream from left bank with weir in foreground and large upstream pool in background. Large mid-channel bar can be seen to the right of the image

A number of fish and macroinvertebrate species have been observed at the site and the deep pools downstream of the weir are popular fishing locations. Derwent Angling Association operates fishing rights along the course of the river at Ebchester. Winter birds have also anecdotally been reported in the area and the river is known to be inhabited by otters and herons. The area is used for many other purposes, including boating and canoeing in the upstream pool, use of the pool for sailing model boatcraft, education and leisure. The woodland to the right of the river has a designated footpath which is popular with walkers. A boathouse stands to the right of the upstream pool, which is owned by the National Trust and leased to the

5th Tyne Sea Scouts. The boathouse is a social tie to the river and the focal point of a number of social and educational events.

To the right of the channel, at the point of the weir (see Figure 5.2, no. 12, in Section 5.2.5), some of the flow from the channel was once diverted in order to power a number of mills which ran along a mill race. This channel is now dry and no longer connected to the river. The weir and river are part of the Durham County Council (DCC) Conservation Area, designated to maintain and preserve the historic (dating back to Roman) features of the area. The issue of conservation of the weir is noted in the Durham County Council Conservation Area Appraisal (p 26 2009) as being of significance to the area.

When aiming to predict and/or understand changes to an environment, such as the river around the Ebchester Weir, an understanding of physical processes is necessary. For example, to understand the hydrological implications of a changing weir profile on water level, one must understand the nature of flow through a channel and over a weir, as well as the interactions that the flow has with other fluvial aspects such as sediment dynamics. The current understanding of the processes at play within a river around the site of a weir, and of the expected implications of changing a weir's shape, are discussed below. The discussion of certain elements below, while grounded in academic literature, is further scrutinised by the competence group as a whole, on reflection of the preliminary model results (Chapter Eight). It is this extra dimension of analysis which allows the overall understanding to become a product of co-production.

5.4 Review of the uses and impacts of in-line channel weirs on flow, sediment, morphology and ecology

This section outlines the academic understanding of the impact that weirs have on flow, morphology and ecology within a river, both upstream and downstream of a barrier. The impacts to ecology provide important contextual setting due to their heavy weighting in river management legislation in the UK and Europe (primarily through the WFD, and the EA's implementation of it) and therefore, require some attention here.

5.4.1 Use of weirs

"Weirs are bed fixing structures that raise bed levels upstream, they can instigate erosion downstream. Fixed weirs are energy absorbing structures that decrease the capacity of flow to transport sediments" Downs and Gregory (2004, 40)

Weirs exist in some form on most of the world's rivers and the UK saw a sharp increase in numbers during the industrial revolution (Lucas and Frear, 1997). Weirs have been used for many centuries and have been a popular river management tool until very recently. The most common purposes of weir installation include the increase of water depth, whether for off-feed and irrigation (e.g. Walker *et al.*, 1992; Ghosh *et al.*, 2009; Wasserman *et al.*, 2011), hydro-electric generation (Poulet, 2007), ancient watermills (Poulet, 2007) or stabilisation of flow (Walker *et al.*, 1992). More site specific purposes include the creation of suitable ecological habitat (Downs and Gregory, 2004, 258; Hey 1996, 100; Salant *et al.*, 2012), the promotion of morphological diversity, deflection of flow from eroding banks and encouragement of scour processes in zones subject to sedimentation (Downs and Gregory, 2004, 293).

Many studies which document flow and morphological impacts of low-head weirs do so in order to provide context for assessments of weir impacts on ecological populations. This is partly in response to the growing interest in the effects of low-head weirs which has resulted from legislation such as the EU Water Framework Directive (which encourages actions such as barrier removal in order to achieve good ecological status). Particular reference to the use of weirs for hydro-electricity generation has been made within the literature (e.g. European Renewable Electricity Directive 2001/77/EC) and there is growing international emphasis on the use of low-head dams for this purpose (Lucas *et al.*, 2009). This provides a complication for river management in the EU, as it contradicts the aim of the EC WFD to achieve 'good ecological status', which requires access and availability of high quality habitat for riverine species. 'Chronic fragmentation' (i.e. the continuous division of the river into a number of shorter reaches with obstructions at each end, as described by Lucas *et al.*, 2009) is counter-productive to this goal and therefore the impacts of weirs on stream ecology need to be carefully assessed in order to make effective decisions on the future of dam structures. Therefore, the dominance within the literature of ecological studies will be mirrored to some extent in the present review of the implications of weirs and low-head dams. The effects on flow and morphology will first be outlined, followed by a discussion of the impacts of these physical changes on the ecology and habitat within a river.

5.4.2 Impacts of weirs on river flow, sediment transport and morphology

Some of the documented impacts of large scale impoundments on rivers (which are more widely investigated) are shared with low-head dams and weirs, (although often to a lesser extent). These include increase in water depth behind the dam and decrease in depth below the dam (e.g. Armitage, 1995; Jorde *et al.*, 2008), localised impacts on flow velocity as a result of obstructions, flow quantity and channel morphological changes (Crisp, 1995) and changes to wetted area (e.g.

Jorde *et al.*, 2008). Hydrographs may be distorted when flow is intercepted, with extreme flows being 'buffered' by the storage effect of the dam (or weir) (Petts and Pratts, 1983; Batalla *et al.*, 2004; Brown and Pasternack, 2008; Isik *et al.*, 2008).

Morphology is slower to respond to channel changes and often reaches an equilibrium state after processes such as initial degradation and armouring have occurred (Petts, 1980, 1984). Reduction in sediment availability (downstream) and reduction in the carrying capacity (upstream) are impacts caused by barriers of any magnitude, to varying degrees (Isik *et al.*, 2008; Jorde *et al.*, 2008). Decreased channel width downstream of a flow barrier (e.g. Church 1995; Gilvear 2000; Gilvear *et al.*, 2002, Petts and Gurnell, 2005) and the loss of pool-riffle sequences (Jowett and Duncan, 1990) are common effects of weirs and dams. Impacts with specific relevance to weirs and low-head dams are discussed in more detail in the following paragraphs.

The upstream flow characteristics are used as the reference point for calculation of flow rates over weirs (Dust and Wohl, 2012) and although equations vary depending upon weir type (see Graf, 1998 for a full review), the one used for broad crested weirs (one of the most common forms of weir) is derived from conservation of energy or the conservation of momentum principles but can be presented in a simplified form as (Dust and Wohl, 2012):

$$Q = C^* g^{0.5} W h^{2/3}$$

Where: Q is the flow rate (m^3s^{-1})

C^* is a dimensionless discharge coefficient (-)

W is the crest width (m)

g is the acceleration of gravity (-)

h is the upstream flow depth above the step crest (m)

Equation 5.1

Impacts of low-head weirs on flow and morphology are comparatively small, when considered alongside the effects of large dams and impoundments (Hart *et al.*, 2002; Pohlen *et al.*, 2007). However, low-head weirs can have a number of localised effects on flow velocity and rate (Walker *et al.*, 1992; Walker and Thoms, 1993). Walker and Thoms (1993) record flow that fluctuates daily rather than weekly, monthly or seasonally as a result of weirs (an effect which diminishes after a short distance downstream), as well as causing some profound morphological changes locally within the channel.

There a number of different structural forms for weirs and each has a specific purpose. The type, form and purpose of the weir can cause varying impacts, but the general effects of a stream barrier will be outlined here.

Gurnell (1997) notes that the dominant controls on river channel size and form are discharge and sediment transport regimes, and the character and composition of the channel boundary. The factors which act as controls on river channel size and form are all impacted when a barrier is placed within a channel. Effects occur to both morphology and flow, and are distinctive upstream and downstream of the barrier.

5.4.2.1 Impacts upstream of a barrier

The most visible impacts on flow involve the storage of water behind a barrier, creating a slow flowing pool area (Shields *et al.*, 1998; Mueller *et al.*, 2011) which can propagate upstream for a number of metres or kilometres (Salant *et al.*, 2012), depending upon the hydrology and morphology of the river at that point, as well as on the form of the weir. Gurnell (1997) states that major disturbances to the energy gradient along a river (e.g. weirs) influence flow velocity, and therefore shear stress imposed on the channel boundary. A disturbance such as a barrier perpendicular to flow will cause the depth of flow to increase and the channel to widen (Im *et al.*, 2011), thus reducing velocity and therefore shear stress (or the ability of the flow to move sediment particles) (Tiemann *et al.*, 2004), which results in increased sedimentation rates immediately upstream of the weir (Kondolf, 1997). It is also expected that finer sediment than usual would be deposited as the transport capacity of the flow reduces (Mueller *et al.*, 2011). This may result in a consolidation of fine sediments on the bed (Salant *et al.*, 2012) as well as an elevation of the bed, and further elevation of water level and channel width (Walker, 2001). Tiemann *et al.*, (2004) reported shallower, faster flowing water downstream of small test weirs, with higher than average sediment sizes, as well as bedrock, and an absence of silt, sand and gravel. Salant *et al.* (2012) observed a reduction in the number of riffles and pools upstream of a weir on the Donnor and Blitzen River, Oregon, USA, six years after installation, in relation to an increase in the proportion of fine sediment, and drowning of topographic variability by backwaters.

In the case that there are multiple weirs on one river, sediment eroded from the base of one weir can be deposited behind the next weir downstream (Walker *et al.*, 1992), causing a series of 'sediment waves' and providing even more material than would have been available for deposition behind subsequent weirs. The presence of a *submerged* weir causes a local disturbance or resistance to flow and therefore an increase in the water surface elevation upstream of the weir (Huang and Ng, 2007).

The shape of the weir affects the flow passing over it. Kim (2001) found that rectangular weirs with notches in a straight configuration stabilised flow, creating a resting place in the upstream

pool, which assisted upstream migration of fish, while trapezoidal weirs with zig-zag configurations caused the flow to be unstable, turbulent and with eddy formations, all of which limit the possibility of resting spaces for fish.

5.4.2.2 Impacts downstream of a barrier

Downstream of weirs, scouring by flow with an elevated head is common (Walker, 2001; Tiemann *et al.*, 2004; Salant *et al.*, 2012). This process removes fine sediment from the bed, and combined with a reduced sediment supply (Kellerhals, 1982, 696) causes a lowering of the bed and an increase in the median sediment size (D_{50} : median grain size, or the diameter below which 50% of the sediment has a diameter finer)) (Im *et al.*, 2011). Degradation of the bed and stripping of fine sediment will continue until bedrock is exposed, or until a stable gravel-armoured bed forms (Conesa-Garcia and Garcia-Lorenzo, 2008; Salant *et al.*, 2012), where the D_{50} may be similar to the previous D_{95} (i.e. the diameter below which 95% of the sediment has a diameter finer) or D_{80} , or until slope is reduced to a value where degradation can no longer occur (Kellerhals, 1982, 696). However, Kellerhals (1982, 697) and Salant *et al.* (2012) note that degradation is less likely if it is sediment limited than if it is transport limited (i.e. ability to transport material has a greater impact than upstream supply of material) and depending on a river's transport rate, a relatively small reduction in flows can reduce a river's ability to transport sediment.

Walker (2001) suggests that in times of high flow, some low-head dams may be 'swamped' by gravel in transit and that downstream scour pits may be in-filled, therefore, suggested impacts of weirs on morphology may be sporadic and short-lived, according to Walker (2001). If a weir is submerged, downstream of the weir, water surface elevation decreases due to the acceleration of the flow after passing through, or over, the weir (Huang and Ng, 2007).

Downstream of weir structures, varying water levels may cause a gradual undermining of the banks and eventual block failure, which will lead to retreat of the banks in some locations (Walker *et al.*, 1992). The shape of the weir will affect the type/location of scour, for example, those that are 'V' shape pointing downstream will cause scour pools to occur adjacent to the bank and may cause bank failure (Hey, 1992, 100). A partial width weir will cause scour to occur in the gap where the majority of flow is forced through. Eroded sediment will be deposited locally.

As water flows over the crest of a weir and plunges into the downstream pool, bubbles of air are entrained (if a critical velocity is exceeded) and aeration of the water results (Baylar *et al.*, 2001; Emiroglu and Baylar, 2003). This process serves to increase the oxygen content of the water, decrease the carbon dioxide content and increase pH value. Oxygenation of water is particularly important to fish for respiration and habitat quality, and so in this way, weir structures may

provide local benefits to fish populations. It has been reported that the optimum weir shape for aeration is the broad-crested weir and that rate of air entrainment increases with the longitudinal slope (Emiroglu and Baylar, 2003). The rate of aeration has also been observed to increase with head height and flow rate (Baylar *et al.*, 2001; Emiroglu and Baylar, 2003) and the depth of the downstream pool (Baylar *et al.*, 2001). Baylar *et al.* (2001) suggest that the oxygen transfer that would occur over several kilometres in a river can be achieved in flow passing over a single hydraulic structure.

5.4.2.3 Reduced flow volume

If a weir is used for water diversion, flow will still be slowed upstream as the structure and standing water dissipate energy, although the water level may not be raised in the same way as if all of the flow was passing over the weir. Reduced discharge may cause a reduction in channel size (Kellerhals, 1982, 697), exposure of gravel bars or parts of the bed, altering the wetted perimeter, friction forces and reducing fluvial habitat availability. Compaction may also result from the drying of organic material in interstitial spaces (Tiemann *et al.*, 2004).

5.4.2.4 Weir removal

The removal of in-channel structures such as weirs may have impacts for flow and morphology as significant as those effected by barrier installation. Weirs may be removed for ecological or for aesthetic reasons (Downs and Gregory, 2004, 288), although there may also be good reasons to preserve weirs, such as heritage and social value. When proposing ways of ameliorating the negative impacts of weirs, Downs and Gregory (2004) place focus on providing improvement of access to upstream habitats for fish.

Weir removal can restore the longitudinal connectivity of a channel or reach (del Tánago *et al.*, 2012). Following removal there may be a switch in deposition patterns, so that sediment is eroded upstream, and deposited downstream of the weir site. This may occur so rapidly that it causes the stream to be destabilised (Im *et al.*, 2011). There may also be a decrease in water depth upstream of the weir site and re-instatement of riffle-pool sequences. Im *et al.* (2011) observed an overall lowering of the channel bed, decrease in flow velocity across the whole site, and increase in median grain size, following the removal of a small weir from a Korean stream, suggesting that the decreased velocity resulted in local deposition of sediment from the eroded reach upstream of the weir site.

Changes may also occur to riparian vegetation, which may die, or take root (Im *et al.*, 2011) depending upon the change in water elevation, cross section extent, vegetation type or changes

to the water table. The implications of weir removal are most important for fish and macroinvertebrate populations and are discussed further in the next section.

5.4.3 Impact on ecology

While the impact of large dams on river ecology has been widely documented, less attention has been paid to the impacts of low-head dams and weirs in research (Tiemann *et al.*, 2004; Poulet, 2007; Musil *et al.*, 2012) and by catchment managers (Lucas *et al.*, 2009). Although the individual impacts of large dams may be more profound than those of weirs, the cumulative nature of the impacts of numerous small weirs along a channel may be as significant to ecological populations. Many impacts felt by fish and macroinvertebrates can be induced by river obstructions of any size. In this review, studies of the implications common to both weirs and large dams are outlined, and the impacts most relevant to weirs are subsequently discussed.

Habitat vital for healthy populations of fish and macroinvertebrates is affected by changes in flow characteristics and channel morphology. In simple terms, higher levels of flow cause a greater wetted perimeter and therefore more abundant habitat (Wood *et al.*, 2000), although abundance does not necessarily equate to quality. Flow stability is believed to increase macroinvertebrate species diversity (to a point, see Connell, 1978), therefore, any amount of stabilisation provided by an impoundment may impact upon population structure (Jowett and Duncan, 1990). Availability of fish spawning habitat can be reduced as wetted perimeter downstream of an impoundment is reduced, and the slow flowing water upstream of the impoundment is likely to be silt-laden and unsuitable for spawning. However, as the impacts of low-head dams and weirs are local in comparison to large scale dams, the impacts are less significant. What is of greatest importance where there are weirs, is the physical barrier for migratory fish.

5.4.3.1 Fragmentation, access, and habitat composition

In the simplest form, impacts of weirs cause disturbance to the longitudinal nature of river systems (Jansen *et al.*, 1999; Baumgartner, 2007) and the connectivity along the length of a channel. It has been suggested by a number of authors that channel fragmentation is globally considered as the primary driver of population decline for migratory fishes (e.g. Lucas and Frear, 1997; Nilsson *et al.*, 2005; Masters *et al.*, 2006; O'Connor *et al.*, 2006; Baumgartner, 2007; Poulet, 2007; Wasserman *et al.*, 2011; Musil *et al.*, 2012), this includes lamprey (Close *et al.*, 2002; Lucas *et al.*, 2009) and eels (Poulet, 2007). Gillette *et al.* (2005) describe the assemblage structure of fish as varying along an 'environmental gradient', which changes progressively from the headwaters to the lower main-stem of a river. Anthropogenically, this fragmentation is caused primarily by dams and weirs. Fragmentation can impede the access for diadromous fish to certain

parts of the river (Lucas and Frear, 1997; Nilsson *et al.*, 2005; Chick *et al.*, 2006; Gillette *et al.*, 2005; Baumgartner, 2007; Beatty *et al.*, 2009; Lucas *et al.*, 2009; Meixler *et al.*, 2009), locally modify habitat (and therefore change the populations to which it is most suitable (Tiemann *et al.*, 2004; Gillette *et al.*, 2005; Poulet, 2007; Lucas *et al.*, 2009; Musil *et al.*, 2012), limit habitat availability and can lead to habitat homogenisation (Musil *et al.*, 2012). Access to, and sufficient availability of critical habitats (e.g. for spawning) are critical to the successful life cycles and the conservation of freshwater animal populations, particularly those which display ontogenetic shifts in habitat use (Lucas and Baras, 2001; Lucas *et al.*, 2009) and these life stages may be disrupted as a result of a loss of suitable habitat (White and Rahel, 2008; Beatty *et al.*, 2009; Lucas *et al.*, 2009). A shortage of any of the habitats required by an organism may cause overcrowding and lead to population decline (Wilcox and Murphy, 1985; Law and Dickman, 1998), and the simple barrier to migration can cause reduced species richness in the upper reaches (Reyes-Gavilan *et al.*, 1996; Holmquist *et al.*, 1998; March *et al.*, 2003). Even for fish species that are large enough to surmount in-stream barriers, it is common to find that only the largest individuals negotiate these barriers to utilise the most upstream habitat (Meixler *et al.*, 2009; Wasserman *et al.*, 2011) therefore habitat availability is limited to individuals which may be small, weak or aged (Cairns *et al.*, 2004; Wasserman *et al.*, 2011). It has been suggested that longitudinal connectivity is of such importance to diadromous fish life cycles that many assemblages have declined in distribution and abundance and are even threatened by extinction (e.g. Baras and Lucas, 2001; Duncan and Lockwood, 2001; Lucas *et al.*, 2009).

When moving downstream, fish may sustain injuries when having to pass over weir structures (Bell and DeLacey, 1972; Lucas and Frear, 1997). O'Connor *et al.* (2006) found that while some fish species on the Australian Murray River were able to travel downstream over a weir without sustaining injury, many were deterred from doing so and instead returned to upstream reaches (this has also been documented by Jepsen *et al.*, 1998; Haro *et al.*, 2000; Behrmann-Godel & Eckmann 2003, according to O'Connor *et al.*, 2006).

5.4.3.2 Changes to flow

Dams may affect fishes through alterations to flow characteristics (Lytle and Poff, 2004), and fragmentation of the channel may lead to the development of a series of lentic and lotic environments along its course (Chick *et al.*, 2006). This can lead to breaks in the flora and fauna habitats that naturally would be within a continuum. In this way, they modify the structures and functions of ecosystems (Ward and Stanford, 1995; Postel *et al.*, 1996). The series of lotic and lentic environments will support different types of ecosystem within the river channel. Gillette *et al.* (2005) observed fish assemblages which preferred slow, deep habitat upstream of weirs, and

assemblages of species preferring shallow, swift flowing habitat immediately downstream of weirs (incidentally, this is also common in the presence of large dams, e.g. Kondolf, 1997). Upstream of a weir, flow velocity is reduced and siltation rates are high (Kondolf, 1997; Gillette *et al.*, 2005), while downstream flow velocity is increased, sometimes concentrated into certain areas, and scouring of the bed may occur (Camargo and Volez, 1998; Gillette *et al.*, 2005). When large enough, weirs or dams may reduce flow variation, particularly at high flows (Poulet, 2007), affecting fish assemblage structure by reducing the abundance of species reliant on seasonal variations for different aspects of their life cycle (Bonner and Wilde, 2000; Gillette *et al.*, 2005) and increasing numbers of limnophilic species in pools (Poulet, 2007). For lamprey and other migratory fish, sufficiently high flows to overcome barriers and access to spawning habitat are essential. A reduction in the spawning habitats available to any fish will make them more vulnerable to catastrophic events such as pollution incidents (Lucas *et al.*, 2009). Freeman and Marcinek (2006) and Poff and Zimmerman (2010) have shown that fish communities consistently respond negatively to hydrological alterations (Musil *et al.*, 2012).

5.4.3.3 Encroachment of non-native species

Anthropogenically induced alterations to flow regime and channel morphology can create environments in which non-native species thrive and affect native populations, for instance through predation or competition (Richter *et al.* 1997; Marchetti and Moyle, 2001; Gillette *et al.*, 2005). Poulet (2007) observed greater numbers of non-native fish species, than native species, close to a weir and attributed this to the artificial conditions created by the weir being more favourable to those species that had been introduced to the Viaur River (France). In a study by Beatty *et al.* (2009), it was demonstrated that weirs may also act in favour of native populations, when they become barriers to the migration of non-native species.

5.4.3.4 Cumulative impacts of weirs

As mentioned above, the impacts of low-head weirs may be less dramatic and more localised (Gillette *et al.*, 2005) than those of large impounding dams, but low-head weirs are more numerous than dams (two to four order of magnitude greater, according to Lucas *et al.*, 2009). Therefore, cumulative effects of the low-head weirs are of importance (Poff and Hart, 2002; Lucas *et al.*, 2009; Musil *et al.*, 2012). An increase in number of, and distance between barriers will only serve to increase the negative impacts that have been documented for single structures or single rivers (Baxter, 1977; Ward and Stanford, 1995). Lucas *et al.* (2009) observed a decline in lamprey numbers in the River Derwent (North Yorkshire) and attributed this to the cumulative effect of barriers on upstream migration. Furthermore, they suggest these findings to be of similar magnitude to those of Gowans *et al.* (2003) for salmonids, and Moser *et al.* (2002) for Lampetra

tridentate (Richardson), with specific reference to hydro-electric *dams*. Musil *et al.* (2012) also found that an increase in number of low-head barriers could be associated with an increase in negative impacts on young of the year fish (namely loss of rheophilic species and low Indices of Biological Integrity (IBI)). They go on to suggest that the shorter distances between the barriers further compound the negative impacts, a point echoed by Chick *et al.* (2006).

5.4.3.5 Positive impacts of weirs

There have been cases in which there has been limited impact as a result of channel fragmentation. Chick *et al.* (2006) note that while individuals may experience difficulty in migration, overall community structure is not always altered. They note that geographic range limitations and habitat factors may also affect fish migration, with similar observations made by Dodd *et al.* (2003) and Raborn and Schramm (2003). Downs and Gregory (2004, 258), Hey (1996, 100) and Salant *et al.* (2012) discuss the use of weirs favourably for fish habitat improvement, suggesting that pools may provide areas of shelter for migrating fish and areas of scour can create fast flowing plunge pools.

In recent years, and largely in response to legislation including the EC WFD, attention has turned to the impacts of weir *removal* for fish populations (e.g. Im *et al.*, 2011; Fjeldstad *et al.*, 2012). A study of the removal of weirs in a Norwegian river found the immediate occupation of spawning sites in gravel for Atlantic salmon and a reduction of mortality in eggs, although pike and cyprinids responded less favourably (Fjeldstad *et al.*, 2012). The positive response of the Atlantic salmon was attributed to the improvement in the quality and availability of habitat, particularly, redds. Babbitt (2002) notes, however, that weir removal can be controversial, socially and economically. Im *et al.* (2011) observed a change in grain size distribution, bed elevation and cross section following weir removal, which led to an improvement in habitat suitability for (and an increase in numbers of) some fish species studied, while others, which preferred slow flow and silty conditions, declined.

5.4.3.6 Effects of weirs on macroinvertebrate communities

Most of the literature aimed at assessing the impacts of low-head weirs has been focused around fish assemblage (Pohlon *et al.*, 2007). However, some studies do report on the implications for macroinvertebrates. Because of the smaller habitat scale required for macroinvertebrates, the effects of a weir pool or downstream reach can be comparable to the effects of a large reservoir. Tiemann *et al.* (2004) found that macroinvertebrate abundance was lowest in test sites which were shallow and fast flowing (i.e. downstream of a weir) and evenness was lowest in deeper, slow flowing sites (i.e. in a weir pool), although overall richness was not affected by weirs, within

their study. They observed that sensitive, lotic taxa were less abundant at sites both downstream and upstream of a weir, than they were at the reference site, suggesting that the low-head dams had negatively impacted upon the habitat quality of the Nesho River. Similarly, Pohlen *et al.* (2007) found that while there were slightly modified invertebrate downstream drifts behind a weir, the barrier had limited impact on the diversity of invertebrate communities upstream and downstream of the weir. Changes to macroinvertebrate community compositions can have indirect impacts on the overall ecology of the river by impacting the food sources available for fish (Baumgartner, 2007). Fish relying on a diet of macroinvertebrates which are no longer present must either alter their diets, be displaced, or perish.

This review has documented the impacts of inline weirs on channel flow, morphology and ecology, and outlined the necessity to understand these impacts for effective management. The specific impacts of a weir depend upon the existing channel shape, flow regime and sediment composition of the river, but all structures serve to increase water level and sedimentation upstream, while downstream they cause a stripping of fine sediment and scour in the fast-flowing, shallow channel. The main ecological impact is the physical barrier for migratory fish, and the creation of discrete lentic and lotic environments in close succession. The WFD suggests that all unnecessary, anthropogenic barriers should be removed from streams, but this process in itself could disturb ecosystems which, although not entirely 'natural', have developed and been established for decades, or centuries, alongside weir structures.

5.5 Chapter summary and Ebchester Weir Research Group's research plan

In this chapter, the experiential and scientific knowledge possessed about the River Derwent, and specifically, the area around Ebchester, as well as process understandings and the implications of channel damming were presented and used to formulate research objectives and a research approach.

The findings from the first three competence group meetings were presented and were found to fit into five main categories, which are: public concerns and questions; knowledge of the history of the river/area; knowledge of the current processes at work in the river and around the weir; social aspects of the weir within the community and external controls on management approaches. The group were also able to offer viable management suggestions for the area, and

when coupled with the 'scientific capabilities' of the project, these suggestions led to a number of research objectives for further exploration. These include:

1. **Determination of the impact of a new weir form on the water level behind the weir and whether this would increase the capacity for using the pool for boating purposes**
2. **Assessment of the impact of a new weir profile on sediment accumulation both upstream and downstream of the weir.**
3. **Investigation of the implications of the proposed removal of dense vegetation from the mid-channel bar and a consideration of how this would affect water conveyance through the reach**

This chapter has introduced the hydrological, morphological and ecological characteristics of the River Derwent, which lies on the border of County Durham and Northumberland. The regulated river has experienced a 'dampening' of the extremes in the hydrograph since impoundment and the ecological state of the river has also changed in response. The physical, environmental and social features of the chosen study site of Ebchester were outlined and the issue of the degrading weir was highlighted as being of great importance to the community.

In order to both provide context for the knowledge that has been developed so far, and to inform the subsequent investigative and analysis processes, a review of the roles and impacts of weirs and low-head dams was conducted. This review highlighted some of the primary impacts of weirs which include local changes to flow characteristics, sedimentation and deposition upstream and downstream of the weir, respectively, and the physical barrier posed primarily to migratory fish species, which reduces usable habitat and therefore alters species assemblage.

The availability of quality habitat for fish and macroinvertebrates is a focal point in many legislative and management structures, not least the EC Water Framework Directive. The WFD requires the evaluation of human impact on water bodies, and the continuity of river systems is one of the hydromorphological elements used to assess stream quality (Mueller *et al.*, 2011). Therefore, an understanding of the implications of Ebchester weir, in a number of states (e.g. restored, degraded) would not only be of value to the community group, but to the wider appreciation of weir implications for river ecological status.

Following discussion with the competence group which aimed to draw a link between the knowledge possessed, the current concerns, and the research options available, it was decided that a hydraulic modelling approach would be used to model flow and sediment transport within

the River Derwent (and specifically focused on the area around Ebchester weir) to address the EWRG objectives outlined above. The results of the modelling process would be shared among the group and reflections, feedback and discrepancies between model output and local understanding would help to focus model development and application. The next chapter will review the standardised approach to hydraulic modelling within academic research, and present the foundation for the modelling approach used in this study

Chapter Six

The fundamentals of hydraulic modelling

6.1 Overview of environmental modelling

There are many reasons and applications for environmental modelling, ranging from global scale climatic simulation, to sub-global simulation of glacial development/devolvement, to catchment scale hydrological routing, down to prediction of micro scale habitat changes. Lane (2003) suggests three main uses of modelling which can be applied to most environmental contexts and are based around the re-creation of one or more environments: i) past environments which have not been monitored or reliably reconstructed; ii) present environments which are inaccessible for monitoring or observation, iii) future environments and their response to certain scenarios. This section begins with a general overview of environmental modelling, leading to a focused discussion of hydraulic modelling for the purposes of river flow analysis.

There exists a plethora of environmental models, but most originate in the same way, beginning with a conceptualisation of the system in question, and developing into either an empirical, or a physically-based (also termed 'numerical') representation of the conceptualised system. The conceptual model contains a 'statement of the basic interactions between all the components of a system' (Lane, 2003), in other words, a description of how a system is believed to operate based on the flows between components which may cause either positive or negative feedbacks. Empirical models involve making and using observations of phenomena to construct relationships between those phenomena, whereas physically based models 'use the conceptual model to define links between fundamental physical, chemical and occasionally biological principles, which are then represented mathematically in computer code' (Lane, 2003). Hydraulic modelling is predominantly conducted through physically based models and these have the advantage of

representing how a system may work by accounting for feedbacks between the Newtonian rules of storage, transport and transfer (Lane, 2003).

Within catchment studies, numerical models can be divided into two categories: hydrologic and hydraulic. Hydrologic models consider the routing of water over the landscape (and usually to the river channel) after it has fallen in some form of precipitation, whereas hydraulic models represent the routing, magnitude and inundation extent of that flow once it has reached the river channel. Hydrologic models can also be used to determine input boundary conditions for hydraulic modelling studies. The focus of this chapter and of the approach used in this study is on hydraulic modelling as the primary research questions lie at the local/reach scale and with the river channel and floodplain rather than the catchment.

This chapter will first review the approach to hydraulic modelling in one, two and three dimensions and consider the most appropriate level of analysis for different purposes. It will then outline some basic principles of the physics of flow, including the classification of flow types and flow regimes. A description follows, of how flow is represented mathematically through the continuity and momentum equations, with specific reference to a one-dimensional modelling approach and the importance of parameterisation and roughness in 1D modelling is discussed. The role of sensitivity analysis and error, verification and validation in the modelling process will be outlined and it will conclude with a review of the approach to representing sediment transport with 1D hydraulic models. The general introduction to modelling in this chapter will set the context for Chapter Seven, where I will discuss in detail the specific modelling approach used in this study.

6.2 The physics of flow

Open channel flow is that which flows through a non-enclosed channel and has a free surface – i.e. the surface of separation between air and water. In this case the pressure acting on the free surface is equal to atmospheric pressure (Graf, 1998). Flow within an open channel can be classified in two ways depending on the length and scale of interest. *Steady* flow occurs when velocity and flow depth are constant over time. If these variables vary in time, flow becomes *unsteady* and discharge is no longer constant. Although open channel flow is rarely steady, because temporal variation is often slow, it can be assumed that flow is steady over short intervals. When flow depth and velocity remain constant in space, flow is considered to be *uniform*. A uniform flow requires the line of the bed slope to be parallel to the free-water surface.

When the bed slope is not parallel to the free-water surface slope, the flow becomes non-uniform (or varied). This change in bed slope may occur slowly from one section to another, in which case the flow may be considered as *quasi-uniform* (Graf, 1998). If the flow depth and velocity change quickly in space (such as at a weir, abrupt change in channel width or hydraulic jump), the flow will become *rapidly varied*. It is possible for a steady flow to be non-uniform and vice versa.

6.2.1 Froude number

The physics of open channel flow is governed basically by the interaction of a number of forces (namely: inertia; gravity; friction (i.e. viscosity and roughness)) acting on the fluid body. These interactions can be represented by some dimensionless numbers to classify flow type.

The Froude number defines the ratio between gravitational and inertia forces and is represented as:

$$Fr = \frac{U_c}{\sqrt{gL_c}}$$

Equation 6.1

Where Fr is the Froude number (-)
 U_c and L_c are characteristic velocity (ms^{-1}) and length (m), respectively (LT^{-1}) (U_c may be considered as U , and L_c as hydraulic radius, R_h)
 g is gravity (LT^{-1})

The *Froude number* is used to classify flow in terms of surface wave behaviour: when $Fr < 1$, the flow is *subcritical* which means that wave celerity may exceed flow velocity, allowing surface ripples to flow upstream. When $Fr > 1$, inertial forces dominate and flow is *supercritical* (torrential). In this case, waves can only travel downstream, and do not affect upstream flow. Waves in supercritical flow may become unstable and break, resulting in large energy losses. If $Fr = 1$, the inertial and gravitational forces are in equilibrium and flow is *critical* (Singh, 1996).

6.2.2 Reynolds number

The ratio between friction and inertia forces determines whether flow is laminar or turbulent and is expressed by the *Reynolds number*:

$$Re = \frac{\rho ul}{\mu}$$

Equation 6.2

Where: Re is the Reynolds number (-)
 ρ is the density of water (kg/m^3)
 u is velocity (m/s)

R is the hydraulic radius (l) (in wide, shallow channels, can be approximated to mean depth) (m)
 μ is the dynamic viscosity of water (-)

When the viscous (friction) forces are dominant, $R_e < 500$ and flow is *laminar*, in which streamlines are smooth, linear and 'slide' over one another without interaction (although rare in open channel flow). At $R_e > 2000$, flow becomes *turbulent*. In this case, the inertial forces are dominant and the flow experiences random secondary motions and interaction between layers (as a result of the formation of eddies). Flow is considered as *transitional* when $500 < R_e < 2000$.

Combining the classifications of flow based on the Froude and Reynolds numbers, four flow regimes can be defined:

Subcritical-laminar	$Fr < 1$	$R_e < 500$
Subcritical-turbulent	$Fr < 1$	$R_e > 2000$
Supercritical-laminar	$Fr > 1$	$R_e < 500$
Supercritical-turbulent	$Fr > 1$	$R_e > 2000$

6.2.3 Velocity

Velocity varies within a channel profile, increasing from zero at the bed, approximately logarithmically towards the free-surface, with the greatest velocity occurring just below the free surface (Graf, 1998), Figure 6.1.

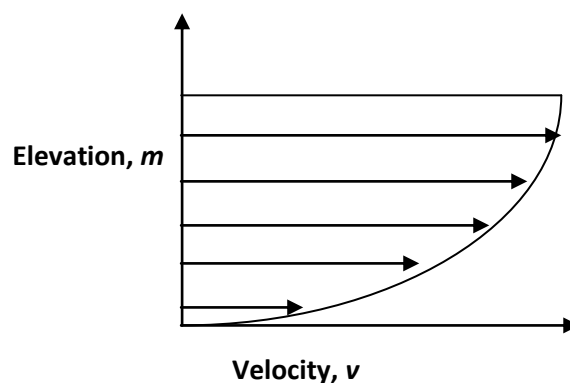


Figure 6.1 Velocity in open channel flow

In open channels, flow is generally turbulent and velocity, $u(x,y)$ can be considered close to average velocity, $U(x)$ (Graf, 1998). Therefore, flow in the steady state can be considered as one-dimensional and average velocity can be deduced in a number of ways:

$$U \approx (0.8 \text{ to } 0.9)u_s \quad (\text{formula of Prony})$$

$$U \approx 0.5 (u_{0.2} + u_{0.8}) \quad (\text{formula of USGS})$$

$$U \approx u_{0.4}$$

Where $u_{0.2}, u_{0.8}, u_{0.4}$ and u_s are velocities (m/s) at given positions within the water column, where 0 is the bed and 1 is the free surface

Determination of whether flow is uniform/non-uniform, steady/unsteady, what velocity is and ultimately, what flow regime these features create, are the basic processes that need to be represented in hydraulic modelling. The next section will introduce various types of hydraulic modelling and discuss the merits and limitations of each.

6.3 Review of one, two and three dimensional models

Hydraulic models operate in one, two or three spatial dimensions. Three dimensional models consider the components of flow in the downstream (u-), cross-stream (v-) and vertical (w-) directions. Two dimensional approaches typically involve integration of the flow field over the depth to produce depth-averaged values of the velocity (Bates and Anderson, 2001), i.e. velocity is predicted in the downstream and cross-stream directions, but is averaged over depth. The 2D shallow water equations are typically used for flows with a high width depth ratio (making them suitable for overbank flood flows), while 1D models are used for wave routing in which lateral and vertical velocity variations are assumed negligible. This means 1D models are well suited to in-bank flow, where they predict water depth for a given cross section, making them a suitable basis for standard hydraulic river models such as HEC-RAS, MIKE11 and ISIS (Bates and Anderson, 2001). This section will discuss the merits, limitations and applications of one, two and three dimensional models.

6.3.1 Three dimensional models

There are distinct advantages to the use of three dimensional models, which consider the downstream (u -), cross-stream (v -) and vertical components of flow (w -). Such advantages include their capability of representing complex hydraulic flow processes such as secondary circulation in the channel and its effect upon the vertical variation in velocity (Horritt, 2000). However, there are drawbacks to this level of complexity, including the high-level of computational cost (and therefore time) necessary to deal with the high dimensionality, which limits their use to in-bank flows, over short reach lengths (Horritt, 2000). Knight and Shiono (2001) suggest that more important than the heightened understanding of the three dimensional hydrodynamics of overbank flow is the appreciation of the importance of the variability imposed by the hydrology in channel/floodplain interactions. Some 3D effects can be represented in 2D approaches as energy loss processes (Sellin and Willets, 1996).

Three-dimensional representation of flow is computationally demanding and costly, and for most applications is more complex than necessary. For this reason, use of 3D models is generally limited to research practices, and for most practical, industrial applications, the use of 1D and 2D models is the dominant approach.

6.3.2 One and two dimensional models

Within channel and floodplain modelling, particularly beyond the research context, model complexity is limited to two and one-dimensional approaches. In 2D modelling, the 3D equations are simplified (see Lane, 1998 for a detailed review), and flow characteristics are depth averaged (u , v), while for 1D models, water depth at a given cross section is calculated and used to define flow under specified circumstances. There has been much debate about the optimum level of complexity and there are supporting arguments for both 1D and 2D approaches. Horritt and Bates (2001) suggested that while flood and flow modelling were important tools for hazard management, there was little consensus around the level of data and modelling complexity that was appropriate for floodplain models, this uncertainty was reiterated by Tayefi *et al.* (2007), Apel *et al.* (2009) and Neal *et al.* (2012). Up until the last decade, 1-D modelling of reach scale floodplain inundation has been commonplace (Bates and DeRoo, 2000). One dimensional models such as HEC-RAS (from the US Army Corps of Engineer's Hydrologic Engineering Centre, HEC, 2002), ISIS, MIKE11 (developed at the Danish hydraulic Institute, DHI, 1997), ONDA and FLUCOMP use cross sections perpendicular to the flow direction, making them well suited to parameterisation with the use of traditional field survey methods (Bates and DeRoo, 2000) and have been the industry standard tool for a number of years.

While it has been suggested that within-channel modelling can be sufficiently accurate using one-dimensional approaches (Tayefi *et al.*, 2007), once flow enters the floodplain, modelling flow routing over the floodplain, and the interaction between the channel and floodplain are less reliable at the one-dimensional scale (Pappenberger *et al.*, 2006; Chatterjee *et al.*, 2008). This is because flood inundation is strongly influenced by topography and shallow floodplain gradients mean that small errors in modelled water surface elevations can cause large errors in predicted inundation extents (Bates and DeRoo, 2000). Bates and DeRoo (2000) suggest that at the 1D scale, areas and topographical features between cross sections are not explicitly represented. 1D models tend to be more sensitive than more complex models to changes in parameters such as roughness (Pappenberger *et al.*, 2006), but as highlighted by Horritt and Bates (2002), friction parameters can be used to compensate for different process representations and are not simply parameterising the bed friction terms.

Consequently, there has been a shift towards the use of 2D models in the last decade (e.g. Horritt and Bates, 2002), examples include FLO 2d (O'Brien, 2006), RMA2 (King *et al.*, 2001), MIKE-21 (DHI, 2000), DELFT-FLS (Hesselink *et al.*, 2003) and TELEMAC-2D (Horritt and Bates, 2001). Two dimensional models have a number of advantages. Firstly, they can provide higher order representation of river hydraulics, more consistent with known processes (Bates and DeRoo, 2000). Second, they include a continuous representation of topography. Third, improved accessibility to 2D flood maps encourages the use of the 2D models, whereas point measurements of stage or discharge are more compatible with 1D models (Horritt and Bates, 2002). Horritt and Bates (2002) note that while 1D models can predict flood inundation extents adequately in some scenarios, 2D models are sometimes preferable, for instance when hydraulic processes such as turbulent momentum exchange between channel and floodplain waters are significant.

However, 2D modelling is not without limitation. 2D models tend to have higher computational costs (Bates and DeRoo, 2000; Chatterjee *et al.*, 2008) and are less well suited to parameterisation with traditional cross section surveys (Bates and DeRoo, 2000, Apel *et al.*, 2009 also note the difficulty in parameterisation as an ongoing obstacle). Until recently, the application of 2D models has been limited by the lack of high resolution topographic data (Horritt and Bates, 2001), although this is now much improved thanks to SAR (synthetic aperture radar, Horritt and Bates, 2002), LiDAR (Tayefi *et al.*, 2007) and satellite imaging.

Therefore, hybrid 1D-2D models, in which in-channel flow, which is dealt with by 1D formulations, is coupled with the more complex representations required on the floodplain through 2D models

(Chatterjee *et al.*, 2008), has been advocated widely (e.g. Chatterjee *et al.*, 2008; Apel *et al.*, 2009; Finaud-Guyot *et al.*, 2011). Examples of such models include LISFLOOD (Bates and De Roo, 2000), SOBEK (from Delft Hydraulics, described by Dhondia and Stelling, 2002), MIKE FLOOD (Rungo and Olesen, 2003). Chatterjee *et al.*, 2008 compared the performance of a 1D and a 1D-2D coupled model in predicting flood inundation in a polder (flood storage area). They found that both models simulated similar water level and discharge values in the channel but slightly different flow processes within the polder itself. They concluded that due to the computational time and preparation efforts required for the 1D-2D model (which were closer to those of a 2D model than a 1D model), that use of a 2D model would only really be beneficial when the study of dynamics within the polder were of particular interest. Finaud-Guyot *et al.* (2011) suggest that some standard 1D-2D coupled models are still lacking in that they account only for mass transfer, and not momentum transfer. They propose a new version of the 1D-2D approach which fully considers momentum transfer between the channel and the floodplain.

A number of authors have also questioned the comparative role of the quality of data sets and model complexity. Tayefi *et al.* (2007) note that simplified 2D equations, when used with high quality topographic data sets may produce results with similar levels of performance than more complicated models. Data set quality should also be considered when selecting the appropriate model complexity. For instance, a model which can capture complex hydraulic processes is essentially useless if no suitable data exist for the purposes of validation or if topographic data for parameterisation is of poor quality (Horritt and Bates, 2001). Conversely, a high quality data set would have limited usefulness in a crude model.

While 2D and 1D-2D models are becoming more popular within research, they have only recently become used as a tool in industry (e.g. LISFLOOD, used by the Environment Agency for some of its flood extent modelling assessments: LISFLOOD web page: <http://www.bris.ac.uk/geography/research/hydrology/models/lisflood/>), and 1D models still dominate the industrial scene. In Section 105 of the Water Resources Act 1991, the Environment Agency was required to assess flood impact in policy development. Numerical models are one of the primary tools used for this task, but to apply these for all of the rivers within England (the area of jurisdiction for the Environment Agency), would be phenomenally time consuming and computationally costly. Little predictive ability is lost when modelling in 1D at such scales because of the complexity and uncertainty involved in selecting appropriate parameters for 2D and 3D models (Romanowicz and Beven, 1998; Perrin *et al.*, 2001). Therefore, 1D models remain the industry standard approach and currently implemented policies and management practices have

been based around outputs from 1D models for some time. Due to the current widespread familiarity with 1D models and the strengths they offer in the modelling of in-channel flow, the 1D model HEC-RAS has been chosen as the focus of this study and consequently, the following discussion of the mathematical representation of flow will be focused on one dimensional modelling. The reasons for the model choice for this specific study will be explored in more detail in Section 7.4.

6.4 Mathematical representation of flow

All flow models use some version of the continuity and momentum equations to represent flow in an open channel. This section outlines the standard representation of flow used in 1D models, starting with the most basic expression of flow (as a function of velocity and area), and going on to describe the continuity and momentum equations in more detail.

6.4.1 Basic equations for channel flow

The simplest expression of flow is:

$$Q = vA$$

Equation 6.3

Where Q is discharge (m^3s^{-1})
 v is velocity (ms^{-1})
 A is cross sectional area (m^2)

However, as A can vary as a function of downstream distance (x), we must consider some fundamental laws of physics when assessing flow within a stretch of open channel. The laws of the *conservation of mass* (continuity) and the *conservation of momentum* underpin the analysis of open channel hydraulics. All hydraulic models are based on the continuity equation and the Navier-Stokes momentum equation. In response to the above discussion, the focus of this section will be on the simplified, 1D approach, however, detailed discussion of two- and three-dimensional approaches can be found in Lane (1998) and Bates and Anderson (2001).

The principle of mass conservation (continuity equation) states that mass cannot be created or destroyed. Assuming that water is an incompressible fluid with a density that is minimally impacted by pressure (remains constant at 1000kg/m^3), the principle of mass conservation can be applied to flow in open channels, using volume (Q) as a proxy for mass. Therefore, variation in the volume (or mass) of water in a section of an open channel, for a given time, must be

equivalent to the sum of the inputs and outputs of that section and is represented by a standard continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0$$

Equation 6.4

Where Q is the flow discharge (m^3s^{-1})
 A is the flow area (m^2)
 q is lateral inflow (m^3s^{-1})

This general continuity equation can be expressed for steady flow as (Lane and Ferguson, 2005):

$$0 = -\frac{d(vA)}{dx} + i = -v\frac{dA}{dx} - A\frac{dv}{dx} + i$$

Equation 6.5

Where: i is the input from (or negative, if loss to) storage per unit distance downstream

and for unsteady flow as:

$$\frac{\partial A}{\partial t} = -v\frac{\partial A}{\partial x} - A\frac{\partial v}{\partial x} + i$$

Equation 6.6

As well as the continuity equation, the equation of the conservation of momentum is required to predict flow in an open channel. This is outlined below.

The law of the conservation of momentum is based on the premise that a body will maintain its state of rest or uniform motion unless acted upon by an external force. In principle, for an incompressible fluid, the rate of change of momentum through time at a point is a function of the spatial change of momentum, plus sources (Lane and Ferguson, 2005):

$$\frac{\partial(Av)}{\partial t} = -\frac{\partial(Av^2)}{\partial x} + \text{sources}$$

Equation 6.7

These sources are pressure gradients, potential energy and friction that cause energy expenditure:

$$\frac{\partial(Av)}{\partial t} + \frac{\partial(Av^2)}{\partial x} = -Ag \frac{\partial h}{\partial x} + gA (S_o - S_f)$$

Equation 6.8

Where

- t is time (s)
- x is the length of the reach (m)
- v is velocity (ms^{-1})
- g is gravitational acceleration of 9.81 (ms^{-2})
- h is mean flow depth (m)
- L is lateral inflows and outflows (m^3s^{-1})
- S_o is the bed slope of the channel (defining the potential energy term) (-)
- S_f is the friction slope (defining the friction term) (-)

It is usually assumed that flow is locally uniform, allowing the use of uniform flow equations to be used in defining the friction term (Lane and Ferguson, 2005), so that terms such as the Darcy-Weisbach equation can be used:

$$S_f = \frac{(v^2 f)}{8gR}$$

Equation 6.9

Where

- R is the hydraulic radius (m)
- f is the friction parameter (-)

In addition to the continuity, momentum and friction equations, a model requires some representation of the initial conditions of the channel, known as boundary conditions which are discussed in the next section.

6.4.2 Boundary conditions

The above calculations often form the basis of hydraulic models for flow routing. In order to represent the environment within a model, the user must provide information as boundary conditions, which can be defined as 'the physical description of the catchment and the initial distribution within it' (Nash and Sutcliffe, 1970). For a 1D model the primary boundary conditions are flow (input and output), topography and roughness.

All flood inundation models work with discharge and water level as upstream, downstream and/or internal boundaries (Pappenberger *et al.*, 2006). In the absence of velocity data (as is usually the case), users of 1D models such as HEC-RAS, ISIS or MIKE 11, substitute velocity data

with an upstream discharge hydrograph, which provides a link between measured depth and cross-sectional average velocity (Pappenberger *et al.*, 2006). It is common for water level data to be recorded in the field and used in a rating equation (based on a known cross section), to determine discharge (although this approach is not without limitation, see Pappenberger *et al.*, 2006). Therefore, input boundary conditions can be entered in the form of a flow hydrograph, stage hydrograph or stage-flow hydrograph. Output boundary conditions may be given in the form of flow, stage or stage-flow hydrographs, as well as a rating curve or normal depth (derived from the slope between the final two cross sections). These data are used to determine the amount of water flowing through a given point at a given time, based on the principle of the conservation of mass.

Topography (and therefore slope) is used as a boundary condition to determine how water is conveyed from one stretch to another and the shape of the channel determines the predicted water depth, which is then used to calculate predicted discharge. In a 1D model, topography is portrayed as a number of cross sections, normal to the direction of flow. Issues with the use of cross sections include the difficulty in accessing some locations which may be of significance, in order to obtain a cross section, and in that the cross section is not a permanent feature and can change over time in response to flow/flood events (Pappenberger *et al.*, 2006). Despite this, the cross section is often entered as a fixed term in the model. Spacing of cross sections impacts upon model output and if insufficient empirical topographic data are available, the modeller may need to use interpolation functions within a model to create new cross sections between measured ones, which will provide a channel topography which phases from the shape of the upstream cross section to the shape of the downstream cross section.

A measure of roughness also allows the model to determine the level of resistance (and therefore conveyance of flow) from one cross section to the next. Roughness, often applied as a roughness coefficient, such as Manning's n , is used as a parameter with which to calibrate the model, and is fully discussed in the next section.

6.4.3 Roughness coefficients and parameterisation

Hydraulic models require some quantification of the stresses applied to flow from the channel boundaries (i.e. bed, banks, floodplains, which cause resistance to flow, resulting in turbulence and energy loss). Such quantifications are expressed as channel and floodplain **roughness parameters**, and Lane (2005) notes that roughness is a component of topography and one of the fundamental parameters in all aspects of process geomorphology. However, quantification of roughness is not straight forward as the scale of roughness may be different to the scale at which

the model is working, and scale of roughness varies both spatially (Lane, 2005) and temporally. Therefore, hydraulic models make use of *roughness laws*, which use roughness parameters to determine the scale of energy loss as a result of friction.

A number of roughness coefficients have been developed and used as central parameters in hydraulic models. These include Manning's n , the D'Arcy-Weisbach friction factor f and the Chezy coefficient C (Lane, 2005). The Manning's n roughness coefficient is one of the most commonly used in hydraulic models:

$$n = \frac{d^{1/2} s^{2/3}}{u}$$

Where n is Manning's roughness coefficient (-)
 d is depth (m)
 s is slope (-)
 u is velocity

Equation 6.10

Roughness is often represented uniformly for a channel or a reach (Shimizu *et al.*, 1990), but, as noted by Lane (1998), in reality channel roughness is usually spatially variable as a result of grain size and sedimentological structure. In response to the limitations of roughness parameters, the use of a *roughness height* (the distance from the surface at which flow velocity becomes zero) has been advocated (e.g. Nikuradse, 1993) although there may be difficulty in determining where measurements of roughness height should begin. Another approach to accounting for roughness (Manning's n) is that proposed by Cowan (1956) in which total roughness is seen as the sum of contributions from a number of different scales:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5$$

Equation 6.11

Where n_0 is a basic n value for a straight, uniform, smooth channel (-)
 n_1 is a value added to n_0 to correct for the effect of surface irregularities (-)
 n_2 is a value for variations in shape and size of the channel cross section (-)
 n_3 is a value for obstructions (-)
 n_4 is a value for vegetation and flow conditions (-)
 m_5 is a correction factor for meandering of the channel (-)

Lane (2005) suggests that roughness parameters and roughness heights are insufficient, (particularly given the improved access to topographical data in the last decade) because they assume that the only impact of roughness is on the magnitude of momentum loss when, in fact, sub-scale topography may also affect routing by creating blockages. Therefore, Lane promotes

the benefits of new approaches which incorporate topography explicitly, such as the use of ‘numerical porosity’ of a river-floodplain system.

Despite these limitations and advances, roughness parameters remain the dominant tool for accounting for flow resistance in hydraulic models. For the reasons discussed above, roughness value may not simply be applied, but the range of roughness values must be ‘tuned’, through the process of *parameterisation*. Hydraulic models often allow the user to dictate which coefficient should be used and apply distributed representation of roughness (of the same coefficient), to areas within the channel and floodplain (e.g. Mason *et al.*, 2003).

While 1D models are efficient in terms of computing time and data requirements, they are particularly sensitive to roughness parameterisation, causing this process to be one of the most costly and time consuming of the 1D model approach and one which must take precedence.

Wainwright and Mulligan (2004) consider calibration to be ‘the definition of process parameters’ – i.e. the determination of the magnitude of the processes operating within the channel as a result of changes to parameter magnitudes (while calibration may be carried out on other parameters, in hydraulic models and specifically in 1D hydraulic models, roughness is the primary parameter). Through calibration, an optimization of the agreement between model results and observations is achieved, with the aim of improving the objective function (which is discussed below). This is an iterative process in which results from a calibration step are compared with observed results, and further calibration steps are carried out based on the nature of change found in previous steps. When using observed data to calibrate a model, it is important to remember to reserve some data for model validation (see Section 6.5.2). The most sensitive parameters are usually used in calibration first as they will create the most profound changes in result. The main parameter involved in calibration of hydraulic models is the roughness coefficient (e.g. Manning’s n). This is so important due to the many aspects that a roughness coefficient represents (Lane and Ferguson, 2005, 219), and can be complicated by the spatial and temporal variability that cannot always be represented sufficiently within a model. There are limitations to the calibration process. The parameter set to which the model has been calibrated will be the one most reliably predicted, and may be predicted well at the expense of other model results (Wainwright and Mulligan, 2004). Furthermore, because roughness parameters are assumed to represent so many processes, the optimized roughness value may vary significantly from measured or estimated values that are based only on resistance from channel boundaries (Lane, 2005). The skill base of the modeller is important as the task is based on heuristic rules (Vidal *et al.*, 2005) and there may be subjective influences such as knowledge of appropriate

parameter ranges, and models being calibrated based on personal interest in a specific output (which may cause the model to perform very poorly for other results). Therefore it is imperative that any model user fully understands the context from which the model is taken. Where a model contains many interdependent parameters, the calibration process may become very complex. Over-parameterisation is common in distributed models (Refsgaard, 1997) and hydrological models (which have many catchment parameters to consider). Hydraulic models may be less problematic as roughness is the fundamental variable. To deal with the issue of over-parameterisation, a number of automated approaches have been developed, including Global Sensitivity Analysis (GSA) and Generalised Likelihood Uncertainty Estimation (GLUE) (see Ratto *et al.*, 2001 for a review).

6.4.4 Sensitivity analysis and error

To determine the robustness of a model, and the relative importance of each parameter, a sensitivity analysis is carried out once the model has been populated with boundary data (often as part of the calibration process, but it can also be used in benchmarking and once the model has been evaluated, as a test of system sensitivity to environmental changes). Identification of the most sensitive parameters can also help to focus efforts in the calibration stage. The usual approach to sensitivity analysis is to alter parameter values incrementally and to observe the impact on model outputs. The change can be expressed as the proportional change in the model output per unit change in the model input (Wainwright and Mulligan, 2004).

Wainwright and Mulligan (2004) suggest that there are many potential sources of error, propagating at every stage of the investigation, from the very act of data collection where we impact the environment in which we are working (e.g. flow measurements within a river), to the inherent error associated with equipment that we use to collect boundary and parameter data, through to the processing of empirical data for use in the model (e.g. determining flow based on water level and a rating curve). And there is also the modelling process itself, in which the representation of a space will always be some form of simplification (Wainwright and Mulligan, 2004). Within a model, parameters are used as expressions of an influence on the system. How this influence is expressed may involve error if the parameter is required to represent too many aspects of a system, too complex a relationship, if it is estimated rather than measured or, if in reality the parameter value varies spatially or temporally, but is insufficiently represented within the model. In addition to the fundamental input errors, Engeln-Müllges and Uhlig (1996) also describe errors associated with the model, which include: procedural errors (resulting from the approximation of a problem where there is no known analytical solution), computational errors

(from the computer representation of the algorithm) and propagation errors, which are a result of the accumulation of other errors such as input, procedural and computational errors.

Further to the errors associated with modelling, there are a number of uncertainties which may originate from information (lack or abundance of), conflicting evidence, ambiguity, measurement uncertainty and belief (Zimmerman, 2000). The boundary conditions for flow are subject to a number of uncertainties which include the potential for channel cross section to change (Pappenberger *et al.*, 2006). Many input hydrographs are derived from water level and topographic data. The rating equation used to derive discharge uses the shape of the channel cross section, but should the cross section change, the water level will no longer represent flow accurately within that equation. Another major source of uncertainty is the temporal and spatial variability of velocity and velocity distribution in complex patterns, which is not accounted for when relating velocity to cross section to derive discharge (Pappenberger *et al.*, 2006). Further to this, significant errors or levels of uncertainty exist when there is a lack of gauged data and an estimate or forcing function is used to determine boundary conditions for ungauged reaches (Bates and Anderson, 2001), for example, when ungauged tributaries need to be represented within a model. Bates and Anderson (2001) suggest that the magnitude of these errors may be sufficient to 'swamp' all other uncertainties and while the model is capable of representing the problem physics, it may be unable to produce satisfactory forecasts for the reach in question. There are of course practical uncertainties associated with the accuracy of data collection devices and conditions which occur that may go unnoticed if the devices are not monitored (such as sediment accumulation over a cross section, interference to the water level from debris and seasonal growth of vegetation).

There are a number of approaches that have been developed to determine levels of uncertainty in flow modelling: comparison of observed and modelled outputs (Rogers *et al.*, 1985); Generalised Likelihood Uncertainty Estimation (GLUE, Beven and Binley, 1992) and Rosenblueth's Point Estimate Method (Rosenblueth, 1981, as demonstrated by Altarejos-Garcia *et al.*, 2012). A common approach for assessing uncertainty in complex models is the Monte Carlo analysis, in which many scenarios are simulated, and the outputs used to determine probability estimates. It is imperative that uncertainties and potential errors are acknowledged and effectively communicated if hydraulic models are to be appropriately employed. A number of statistical analyses available to quantify model output accuracy are discussed in Section 6.5.2 where the issue of output interpretation and communication of error is also discussed.

6.5 Model application

Within the modelling process, a number of steps are taken in order to assist the model in accurately recreating measured flows (calibration: encompassed in the steps above, and described in Section 7.2.2), to ensure that the model is correctly solving the physical equations (verification) and subsequently ensuring the model can recreate other flows against which it has not been calibrated (i.e. ensuring the model is temporally transferable: validation). The reasoning behind each of these steps is discussed below.

6.5.1 Model verification

Verification is the process of ensuring that a model is achieving the correct solutions of associated equations (Lane and Richards, 2001) through the comparison of numerical and analytical solutions (Oreskes *et al.*, 1994). Lane *et al.* (2005) list a number of criteria for checking that equations are being solved correctly, including: standard of reporting; level of solution accuracy in space; mesh independence testing; determination of solution convergence; solution accuracy in time; specification of boundary conditions; reporting of code, use of benchmark solutions and comparison with experimental results. Analysis of a number of variables can be used to verify a hydraulic model, including computational time-step and input data time interval. For 1D models, cross section interpolation intervals can also be used. When the model does not react to changes in these variables, it can be considered mesh independent, and therefore verified. A common verification method is the use of model resolution. If the model produces consistent outputs within a window of convergence, then it is *spatially* discretisation independent – i.e. within the window of convergence, the outputs are independent of the mesh resolution (for 2D and 3D models) or cross sectional spacing (1D). Variation of computational time-step can be used in the same way to determine whether model outputs are dependent on the frequency of the equations are solved for a given simulation. In all cases, users must find the appropriate balance between model accuracy and computational cost.

The time-step applied to model computations is an important aspect of flow modelling. The solving of the above equations can be set to occur at a range of intervals such as once a second, minute, hour or day. If a model is sensitive to the time-step (or lies outside of the window of convergence), output may vary depending upon the time-step chosen, for example, a time-step of one second may reproduce a hydrograph more accurately than a time-step of one hour. The smaller the time-step, the longer the overall simulation time, but a large time-step may cause the model to become numerically unstable. It is the responsibility of the user to determine the most appropriate time-step in terms of computation time and output accuracy. One option for

compromise is that of a quasi-unsteady flow, in which time-step varies as a function of flow rate so that when changes are likely to be occurring rapidly within the channel (i.e. at high flow), the computation time is great enough to represent the changes that are occurring and when there is less activity (i.e. low flow), the computation interval is low so that overall run time can be reduced without losing important process representation.

In the present study, sensitivity to the above mentioned variables is considered by examining the model response to graded changes in roughness, spatial discretisation (cross section spacing) and computational time-step, altering only one variable at any given time. This sensitivity analysis will be discussed in more detail, and results presented, in Chapter Seven.

6.5.2 Model validation

Following the parameterisation process, and once an acceptable level of predictions has been achieved, the model may be validated. The iterative process of validation involves testing the calibrated model, usually via a split sample approach (Wainwright and Mulligan, 2004) in which model results are tested against new data that were not used in the calibration process, to determine whether the model performs well for the 'unrelated' data. Validation can be used to compare observed data to outputs, to consider to what degree variability in observed data is explained by predictions, and to determine whether the model works sufficiently well to be applied to a scenario for which there are no observed data. If the model results are comparable to the validation observations (e.g. discharge or stage time series), the model can be considered as validated ('suitable for application to other flow events', (US Army Corps of Engineers, 2010a)).

A number of objective functions have been developed to quantify model performance, as a means of validation. These consist generally of a comparison between model outputs, M_i , and observed values, O_i , as outlined in Table 6.1. It is important to consider the rules of each equation and be aware of the assumptions or biases associated with each one when choosing and interpreting an objective function.

Name	Measurement	Benefits, limitations	Equation
r^2 , coefficient of determination	Proportion of variance in the observed data that is explained by model outputs. 1 = all variance explained by model, 0 = no variance explained by model	- Perfect agreement if model consistently under/over-estimates - Sensitive to outliers	$r^2 = \left(\frac{\sum_{i=1}^n [O_i - \bar{O}] \cdot [M_i - \bar{M}]}{\sqrt{\sum_{i=1}^n [O_i - \bar{O}]^2} \cdot \sqrt{\sum_{i=1}^n [M_i - \bar{M}]^2}} \right)^2$
Nash and Sutcliffe (1970)	Measure of mean square error to observed variance. If NS = 1 then error = 0, if NS = 0, error = same as observed.	+ not affected by proportional effects, as r^2 is - Sensitive to outliers	$NS = 1 - \frac{\sum_{i=1}^n (O_i - M_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$
Willmott (1981) index of agreement	Ratio of mean-square error to total potential error. 1 = perfect model fit, 0 = worst model fit	- Sensitive to outliers	$W = 1 - \frac{\sum_{i=1}^n (O_i - M_i)^2}{\sum_{i=1}^n (M_i - \bar{O} + O_i - \bar{O})^2}$
Mean absolute error	Compare RMSE/MAE ratio to 1, to determine extent to which outliers affect model evaluation		$MAE = \frac{\sum_{i=1}^n O_i - M_i }{n}$

Table 6.1 Evaluation of validation statistics for hydraulic models. \bar{M} and \bar{O} are mean measured flow and mean observed flow, respectively. (After Wainwright and Mulligan, 2004)

While comparison of observed and predicted outputs is a common approach to model validation, and has received much attention (as demonstrated by the range of statistical analyses developed to quantify the relationship), Bates and Anderson (2001) warn of the dangers of this ‘external validation’ (in which comparison of observed and modelled flow takes place at outflow points from the modelled domain) when it is difficult to ensure that the validation data and process are independent of the boundary conditions. Therefore, other methods of validation may be used to support the output hydrograph analyses. These may include internal validation or the use of wrack lines. Internal validation involves the consideration of hydrographs produced within the

model to determine whether the model correctly predicts flows at any point within the catchment, rather than just at the end point where predictions have been calibrated against observations. Wrack lines marking the height reached by flood events can be compared to model predicted water levels for the same event. The problem associated with both of these approaches is the limitation of data. Long term gauging of flow data is expensive and requires commitment from a responsible organisation, such as the Environment Agency. Consequently, not all catchments are gauged and when they are, this monitoring is usually limited to one inflow and one outflow point while flow data from within the catchment are rare. The use of wrack lines requires the model user to be able to access a point in the channel immediately following a high flow event and to be able to distinguish the impacts of that event from others. Rykiel (1996) describes a number of other validation methods, which include: face validation; gauging expert response to results; event validity; performance when extreme conditions are tested; analysis of whether the changes of a variable over time are realistic; sensitivity analyses and statistical evaluation. In this study, flows are being recreated retrospectively. This means that no reliable wrack line information exists and the catchment is only gauged at the inlet (Eddy's Bridge) and the outlet (Rowlands Gill) (see Figure 5.3). Stage data exist for the site of Blackhall Mill, but there is no cross section for this site to allow comparison on predicted stages. Therefore, validation by the comparison of the observed and predicted hydrographs at the downstream boundary is the best available option in this case. These comparisons will be quantified using some of the approaches listed in Table 6.1 (see Section 7.2.4). The results will also be discussed with the competence group.

While the terms 'verification' and 'validation' are well understood within the hydraulic modelling community, Oreskes *et al.* (1994) and Wainwright and Mulligan (2004) suggest that when used improperly, or when used with 'non-modellers', the terms can be confusing or even misleading: sometimes used interchangeably (despite actually describing different fundamental processes), and sometimes being mistaken for terms which suggest that the model and its outputs are correct and absolute. Oreskes *et al.* (1994) therefore suggest the use of the terms 'benchmarking' for verification and 'evaluation' for validation. Given that the topics of communication and transparency lie at the core of this study, and that communication of model uncertainty is seen as one of the major challenges to the proper interpretation of scientific findings, the choice of appropriate terms is considered as imperative. Therefore, Oreskes *et al.*'s suggestion for new terminology has been accepted and from hereon, the terms 'benchmarking' and 'evaluation' shall be used.

6.6 Representation of sediment transport in hydraulic models

Once the model can reliably predict flow magnitude and timing, it can then be prepared to model sediment transport dynamics. There are a number of methods for sediment transport prediction including the use of formulae (including modelling), sampling and locally calibrated transport formulae with site-specific observation data (Wilcock, 2001). Discussion of sediment transport estimation is extensive (e.g. see Wilcock, 2001) and therefore only the formulae method (with specific reference to model applications) will be discussed here. Sediment transport formulae generally use grain size and channel geometry along with dimensionless flow parameters to predict transport rate. Strengths in using transport formulae include the ability to predict channel change for conditions other than those presently existing. Limitations associated with estimating transport rates with formulae include underestimation of bedload flux if there is any local spatial variation in the bed or flow (due to the one-dimensional and width-averaged nature of the transport calculations in contrast with the non-linearity of bedload transport laws (Ferguson, 2003)). Another limitation arises from the propagation of errors in measured variables and spatial variability of shear stress (τ_0) (Wilcock, 2001). These errors can be reduced by applying observed bed grain size and topography data, however, collection of such data, particularly for reaches that are subject to regular change can be time consuming and costly.

Similar to the modelling approach for flow, sediment transport equations represent the principles of conservation of mass and conservation of momentum (Mosselman, 2005). The expression of the conservation of mass is straight forward, and reads in a depth averaged form:

$$(1 - \varepsilon) \frac{\partial z_b}{\partial t} + \frac{\partial q_{sx}}{\partial x} + \frac{\partial q_{sy}}{\partial y} = 0$$

Equation 6.12

Where q_{sx} and q_{sy} are volumetric sediment transports per unit width (excluding pores), in the x- and y-direction, respectively (m^2/s)

Where:

- t is time (s)
- x and y are horizontal space coordinates (m)
- z_b denotes bed level (m+ datum)
- ε is the porosity of the bed (-)

Sediment momentum representation, however, is less simplistic because so many empirical closure relationships are required (Mosselman, 2005). As a result, many mathematical models

use simple empirical predictors that relate the rate of sediment transport to local flow conditions (Mosselman, 2005). Therefore, only the basic principle of sediment transport will be outlined here. Detailed discussion of specific equations can be found in van Rijn (1993). A general expression of sediment transport formulae (primarily for unimodal sediment) is through the relationship between an Einstein parameter for sediment transport and a Shields parameter for sediment mobility (Mosselman, 2005):

$$\Phi = \Phi(\theta) \quad \text{with} \quad \Phi = \frac{q_s}{\sqrt{g\Delta D^3}} \quad \text{and} \quad \theta = \frac{\tau}{\rho g \Delta D} = \frac{u^2}{C^2 \Delta D}$$

Equation 6.13

Where C is the Chezy coefficient for hydraulic roughness ($\text{m}^{1/2}/\text{s}$)
 D is a characteristic diameter of sediment particles (m)
 g is the acceleration due to gravity (m/s^2)
 q_s is the volumetric sediment transport per unit width (excluding pores) (m^2/s)
 Δ is the relative submerged density of sediment particles (-) defined by:

$$\Delta = (\rho_s - \rho) / \rho \quad \text{Equation 6.14}$$

θ is the Shields parameter (-)
 ρ is the mass density of water (kg/m^3)
 ρ_s is the mass density of the sediment (kg/m^3)
 τ is the bed shear stress exerted by the flow (N/m^2)
 Φ is the Einstein parameter (-)

In-channel sediment transport is often an additional function provided by hydraulic models (e.g. HEC-RAS) and within these models, the user is offered a number of transport formulae from which to choose. Some common formulae include Meyer-Peter and Müller, (1948); Ackers and White (1972); Parker *et al.*, (1982); Engelund-Hansen (1967); Laursen (1958); Toffaleti (1968), Yang (1973). In a review of the performance of a number of these formulae, Yang and Schenggan (1991) concluded that the Yang formula was the most accurate overall, followed by Toffaleti, Einstein (1950), Ackers and White, Laursen, Engelund and Hansen (based on analyses with river data rather than laboratory data). It should be noted that when estimating sediment transport rates, a greater deal of accuracy can be achieved through appropriate calibration than through choice of formula (Wilcock, 2001). The suitability of each of these formulae with specific reference to this study will be addressed in the next chapter.

6.7 Chapter summary

This chapter has reviewed the application of numerical models in one, two and three-dimensions. It has been demonstrated that 2D and 3D hydraulic modelling offer a higher level of predictability than 1D modelling, although at the expense of computational effort and complex data requirements. 1D models are currently the standard tool used in industrial and policy practice because of their applicability to large spaces with minimal topographic data requirements, although they do require a significant level of parameterisation. The processes of benchmarking (verification) and evaluation (validation) have been outlined and statistical approaches to quantifying model suitability evaluated. The continuity and momentum equations for sediment transport in 1D hydraulic models have been presented and an evaluation of the most appropriate transport formulae has shown that the Yang (1973) formula may overall be the most effective, although there is a strong context dependency.

The above sections have outlined the basic principles and practices upon which hydraulic modelling is based and provides context for the more specific details provided in Chapter Seven of the steps taken to the modelling approach for this study. Chapter Seven will begin by outlining the justifications for a 1-D approach in this specific case, will describe the approach taken and present model results for the case study outlined in Chapter Five.

Chapter Seven

Hydraulic modelling of the River Derwent

7.1 Model selection

In Chapter Six three levels of numerical modelling were reviewed which are available to predict channel flow processes and sediment dynamics. Leading on from the general discussion of hydraulic modelling in Chapter Six, this chapter will first outline the specific approach taken to hydraulic modelling for this study, beginning with a justification of model choice, with a focus on the benefits of the selected model for participatory work. The steps followed for data collection and processing are then outlined before the standard model development process will be discussed (Section 7.2). This will include calibration, benchmarking and evaluation, showing the process followed which enabled the model to be suitable for application. Applications of the model were structured around the EWRG objectives developed in Chapter Five and are presented in Section 7.3, in which the impact of a new weir design on water level and sediment transport will be considered, as well as the potential impact of vegetation removal from the central bar (Section 7.3.3). The chapter will finish with a summary of the findings and a discussion of how they are communicated with the competence group.

A one dimensional modelling approach was adopted for a number of reasons. First, the approach allows the investigation of both flow and sediment dynamics under varying channel conditions, making use of elevation data (in the form of cross sections), while being computationally less costly than a two dimensional model. This allows a greater number of scenarios to be tested (the technical reasons for a 1D model choice are discussed in detail in Section 6.3.2). Second, the specific model chosen (HEC-RAS) is one of the two main approaches used by statutory environmental management authorities in England, namely the Environment Agency (EA), (for

example, to fulfil Section 105 of the Water Resources Act, 1991, in mapping flood risk (Hamer and Mocke, 2002)). Many of the concerns expressed among the competence group members were linked in some way to the management practices of the Environment Agency (see Section 5.2). By demonstrating a process consistent with the decision-making and research processes of the Environment Agency itself, it was hoped the group would gain an improved understanding of the context in which decisions and plans are made. Third, the model is freely available and simple to download to a PC. This allows the model to be demonstrated to, and used with, the competence group on a laptop in a location with which they are comfortable (modelling is likely to be a new experience for most members of the group and it is important that they feel as comfortable as possible in this new task (see discussion in Section 9.5)). Related to this point is the simple approach in terms of use and physical basis (in relation to 2D and 3D models) of HEC-RAS. The model is relatively straight forward in terms of the theoretical basis and it is imperative that the theory behind the model can be communicated to the competence group clearly and in a way that they can understand, in a short time. The simple user interface and application process (once the model has been set up) makes it ideal to allow 'non-expert' users to use the model interactively (it should be noted here that the model was set up and a fixed data set was used with the group – it is unadvisable to offer 'untrained' individuals free use of the software as results may be interpreted incorrectly. The group were simply given the chance to view the model, the process and results, to become familiar with some of the tools that 'certified experts' use). Finally, the model has been used in previous research on the River Derwent and is known to provide satisfactory outputs for flow simulation. This was seen as an important foundation for the development of the model for the current study.

7.2 Methodological approach to 1D flow and sediment modelling

As demonstrated in Chapter Eight, the general approach to any modelling investigation consists of a number of steps which include data acquisition, data processing, model set-up, parameterisation, benchmarking (a form of verification), evaluation (or validation) and finally, application. The following sections will describe how each of these steps was applied in this study and will demonstrate how the model was developed to a state that was considered appropriate for use with the Ebchester Weir Research Group (EWRG).

7.2.1 Numerical data collection

The types of data required for the boundary conditions in hydraulic modelling are discussed fully in Section 6.4. Here, each type of data and the method of collection for this study will be outlined.

7.2.1.1 Flow

The data required for the model consist of topographical data, flow data and roughness data. Flow data were obtained for the River Derwent from EA archives and cover the years 1954 to 2008. As Derwent Reservoir was built in 1966, the data prior to this time were not included in any analyses. Both 15 minute and daily flow data were available for the upstream boundary of Eddys Bridge and the downstream boundary of Rowlands Gill (see Figure 5.3 for locations). The 15 minute data were used in the modelling process. The data are recorded as stage measurements and converted to flow rates by the EA hydrology department using a series of rating equations, which are presented in Equation 7.1 and Table 7.1 (source: <http://www.environment-agency.gov.uk/hiflows/search.aspx>)

$$Q = K(h + a)^b$$

Where: Q is discharge (m^3s^{-1})
 K is multiplier coefficient (-)
 h is height of water (stage) (m)
 a is intercept coefficient (-)
 b is exponent coefficient (-)

Equation 7.1

Rating curve limb	Maximum stage for use with EB equations	Eddys Bridge (EB)	Maximum stage for use with RG equations	Rowlands Gill (RG)
a	0.79	$Q=3.079(h+0.00)^{1.502}$	0.16	$Q=13.723(h+0.00)^{1.294}$
b	1.31	$Q=11.739*(h-0.250)^{2.711}$	0.59	$Q=53.460(h+0.00)^{2.028}$
c	5.00	$Q=21.460*(h-0.520)^{1.878}$	5.00	$Q=44.00(h+0.00)^{1.658}$

Table 7.1 Environment Agency Rating equations used in calculation of discharge from stage data for the upstream (Eddy's Bridge) and downstream (Rowlands Gill) boundaries of the modelled river reach

Flow data were assessed visually using the long term hydrograph to identify a portion of the hydrograph which was considered suitable to be used in model development. Criteria used to select an appropriate hydrograph included the coverage of a range of flows (as suggested in HEC-RAS user manual: US Army Corps of Engineers, 2010a), a hydrograph which begins at low flow,

includes at least one rising and one falling limb of a significant peak, and returns to low flow at the end of the simulation, and one which is of sufficient duration to allow the model to stabilise at the start (in excess of three hours). Once an appropriate hydrograph had been selected (see Figure 7.6), the data files were checked to ensure there were no recordings for instrument errors on the relevant days. A small error in stage can potentially lead to a large error in discharge and make model calibration difficult and inaccurate. This approach was also applied to the selection of data for model evaluation (see Section 7.2.4).

There are a number of ungauged tributaries in the catchment joining the river between the input and output boundaries. The initial aim of accounting for flow in these tributaries by using the Flood Estimation Handbook ReFH (Revitalised Flood Hydrograph, Wallingford Hydrosolutions, 2005) was unsuccessful due to the inaccessibility of catchment parameters required for the ungauged catchments. In the absence of predicted flood hydrographs, the Manning's formula (Equation 7.2) was used to estimate a velocity for each tributary:

$$U = \frac{(s^{\frac{1}{2}} D^{\frac{2}{3}})}{n}$$

Where: U is velocity (m/s)

S is slope (-)

D is depth (m)

n is manning's roughness coefficient ($m^{1/3}s^{-1}$)

Equation 7.2

The calculated tributary velocity and area were then used in the standard discharge equation (Equation 6.3: $Q=va$) to estimate proportional flow for the tributary catchment, based on the flow hydrograph at the input boundary. Initially, the single estimated flow values for each tributary were assigned to HEC-RAS as steady lateral inflows (associated with the nearest downstream cross section to the tributary location). However, this uniform flow over the hydrograph time period reduced the extremity of peaks and troughs in the predicted output hydrograph. Therefore, the estimated flow rate was calculated as a proportion of the long term median flow for the input boundary and a hydrograph for each tributary was calculated as a percentage hydrograph of the gauged input hydrograph. It is acknowledged that this method will introduce a certain degree of uncertainty, however, it is considered the most appropriate way to represent tributary flow in the absence of gauged data and catchment parameters. The error associated with this approach is considered in all data interpretation and is communicated clearly to members of the competence group during the process of deliberation of preliminary results (Chapter Eight). As detailed below, the model was able to predict the output hydrograph reasonably well, which suggests that the total estimated tributary discharge was appropriate.

Therefore, the proportion of estimated flow being input at various locations was the main concern. HEC-RAS allows the input of tributary flow data only at given cross sections, therefore, the level of detail required here was limited to a proportion of the total tributary inflow for each cross section or reach. Being referenced according to Ordnance Survey data, the tributary inputs were assigned to the nearest downstream cross section with confidence. The estimated tributary hydrographs were added to HEC-RAS as lateral inflow hydrographs, in connection with nearest downstream cross section.

7.2.1.2 Topography

Topography in a 1D model is represented by cross sections of elevation normal to the direction of flow. For the wider catchment, 16 cross sections were taken between the upstream and downstream boundaries, at intervals of roughly 1-2km. These cross sections were measured using a Leica 1200 EDM total station and they recorded difference in height and angle of a marked point relative to the base station. The cross sections were geo-referenced using GPS collected coordinates to determine elevation, and their locations are displayed in Figure 7.3.

A high resolution topographical representation of the study area around the weir was required to investigate subtle changes in channel form and flow, in response to different weir conditions and hydrographs. To obtain this detailed representation of the channel, a range of methods were used. A Leica 1200 differential GPS was used to collect coordinates (and their associated elevations) accurate up to 1.5cm (Jaboyedoff *et al.*, 2012) for the area around the weir and the weir itself. Due to a number of environmental factors such as river depth and tree coverage, there were large sections of the reach in which it was impossible to obtain dGPS readings. To account for this, the Leica 1200 EDM was used to obtain cross sections for the shallow, tree covered areas downstream of the weir and a Trimble GS200 Terrestrial Laser Scanner was used to map the banks of the river in the deep pool upstream of the weir. Cross sections of the deep pool were obtained from the Tyne Rivers Trust to complete the data set. When all sources were combined, the points represent cross sections of the study area approximately 1m apart (except for the TRT cross sections, which were approximately 10m apart), for a total distance of 150m.

The dGPS, EDM and laser scanner data required some post-processing before they could be used, and were geo-referenced in order to combine them to produce one data set. The process is summarised in Figure 7.1. The final topographical data set is presented in Figure 7.2.

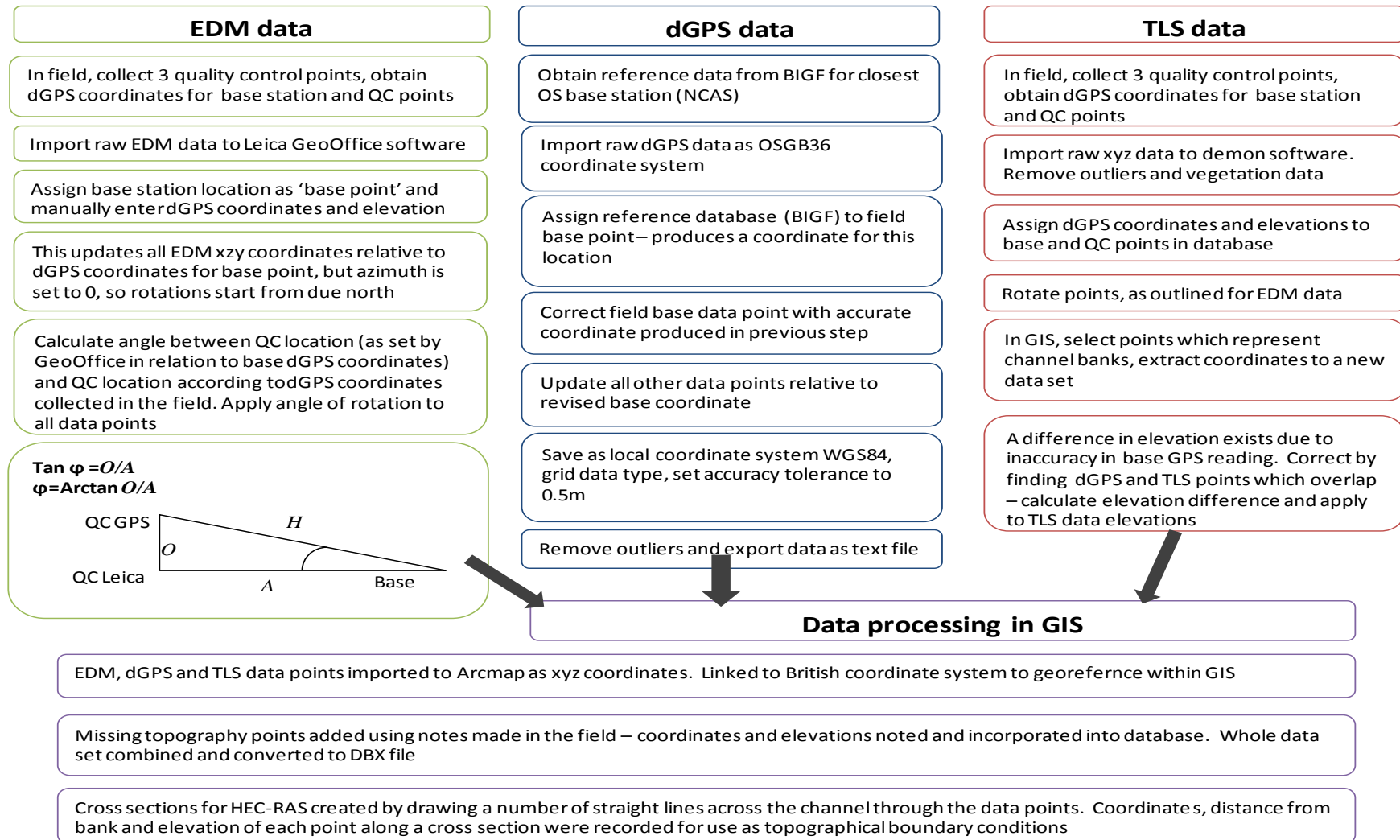


Figure 7.1 Data processing steps following field collection, in preparation for use in HEC-RAS. Box colours correspond to data point colours in Figure 7.2

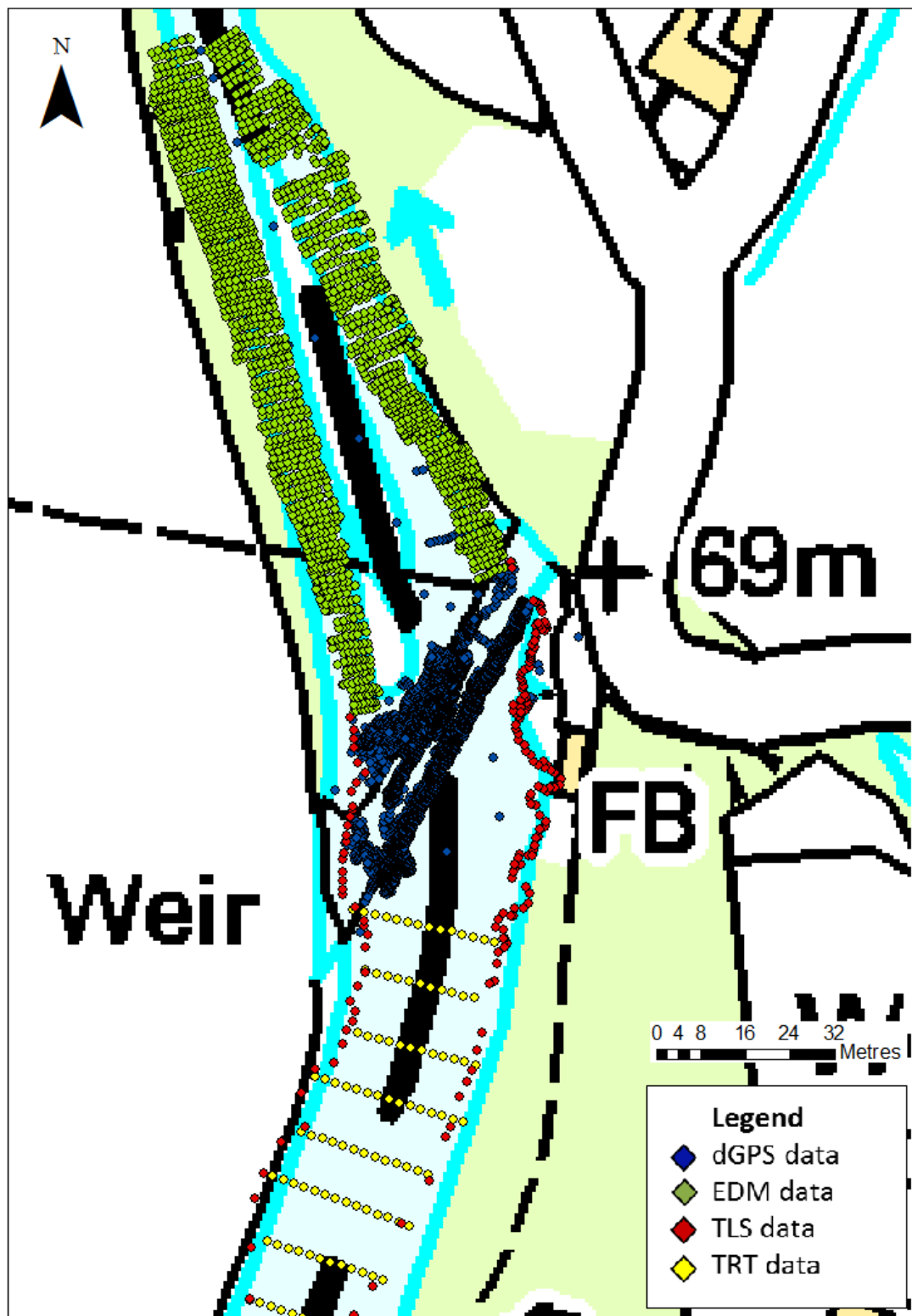


Figure 7.2 Final topographic data set based on dGPS, EDM, TLS and competence group data collation.

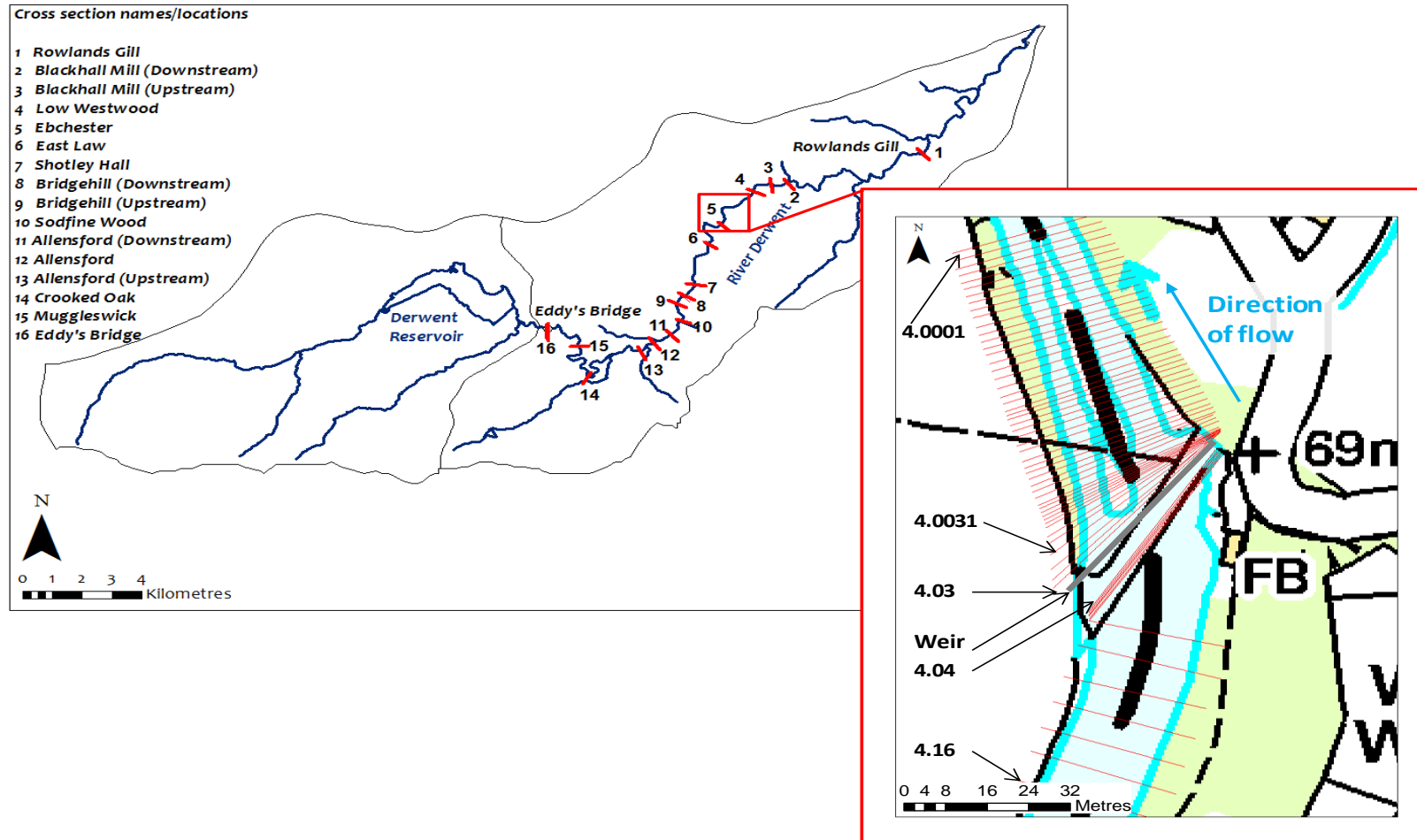


Figure 7.3 Cross section locations for the Derwent Catchment and for the Ebchester Weir study site. Cross sections at Ebchester are numbered 4.16 (most upstream) to 4.0001 (most downstream), as required by HEC-RAS. The weir is flanked by cross sections 4.04 (upstream) and 4.03 (downstream).

In HEC-RAS, weirs are represented using a weir equation. A cross section of the weir is required, as well as other data, as detailed in Table 7.2. The weir profile was created by obtaining a series of top height points for the weir across its length. Gaps in the weir can be identified by changes in height of the top of the weir, and the data set for the original weir was used to design a new hypothetical weir that may exist following restoration, as well as a hypothetical weir profile that may develop, should the original weir be left to degrade (see discussion in Section 7.3 and Figure 7.15 for weir profiles).

Field in HEC-RAS	Description	Value used
Distance	Distance between the upstream side of weir and the first upstream cross section	0.5
Width	Width of the top of the weir from the most upstream to the most downstream point	1.3
Weir coefficient	Coefficient used for weir flow over the weir in the weir equation	2.16
U.S. embankment	Slope on the upstream side of the structure (ratio of horizontal distance to vertical distance)	0.001
D.S. embankment	Slope on the downstream side of the structure (ratio of horizontal distance to vertical distance)	1
Weir crest shape	Used to determine how much the weir coefficient should be reduce when the weir is submerged.	Ogee*
Spillway approach height	Elevation of the spillway crest minus the mean bed elevation just upstream of the spillway	0.4
Design energy head	Energy grade line elevation minus elevation of the spillway crest	0.3

Table 7.2 Data required and values used in HEC-RAS for the weir equation (all values in metres, except ratios). Note: *Ogee shaped weirs are an option in HEC-RAS, the alternative being ‘broad-crested’. The ogee shape depicts a vertical wall at the upstream end, often with a broad, curved top and sloping downstream face, see Kim and Park, 2005, Figure1, for example

7.2.1.3 Roughness

Roughness coefficients were assigned to each cross section by comparing photographs of the study river and banks, with photographs and descriptions provided in a number of literature sources, these included Chow (1959); USGS verified roughness characteristics of natural channels (<http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/index.html>) and the recommendations provided in the HEC-RAS software. This is a common approach to obtaining

roughness coefficients in hydraulic modelling (Chow, 1959; Arcement and Schneider, 1989) but does carry the limitation that interpretation can be subjective. Furthermore, Marcus *et al.* (1992) note that the photographic method is designed for one flow, usually bankfull, and that at different flow levels, roughness may be very different to the roughness at bankfull. For this reason, the process of parameterisation is a fundamental part of the model setup process. The roughness coefficients that were assigned to each of the cross sections are summarised in Table 7.3. HEC-RAS allows the user to assign different values to the channel, left bank and right bank to allow a distinction between channel and floodplain flow. These original Manning's n values were altered during the calibration process, which is discussed in Section 7.2.2.

Cross section number	Left bank n	Channel n	Right bank n	Cross section number	Left bank n	Channel n	Right bank n
16	0.025	0.05	0.08	4.0030	0.1	0.05	0.1
15	0.035	0.045	0.035	4.0029	0.1	0.05	0.1
14	0.035	0.045	0.04	4.0028	0.1	0.05	0.1
13	0.035	0.045	0.04	4.0027	0.1	0.05	0.1
12	0.025	0.045	0.04	4.0026	0.1	0.05	0.1
11	0.035	0.045	0.035	4.0025	0.1	0.05	0.1
10	0.025	0.05	0.025	4.0024	0.1	0.05	0.1
9	0.04	0.045	0.04	4.0023	0.1	0.05	0.1
8	0.035	0.045	0.04	4.0022	0.1	0.05	0.1
7	0.07	0.045	0.07	4.0021	0.1	0.05	0.1
6	0.07	0.045	0.07	4.0020	0.1	0.05	0.1
5	0.07	0.045	0.03	4.0019	0.1	0.05	0.1
4.09	0.03	0.065	0.1	4.0018	0.1	0.05	0.1
4.08	0.03	0.065	0.1	4.0017	0.1	0.05	0.1
4.07	0.03	0.065	0.1	4.0016	0.1	0.05	0.1
4.06	0.03	0.065	0.1	4.0015	0.1	0.05	0.1
4.05	0.03	0.065	0.1	4.0014	0.1	0.05	0.1
4.04	0.03	0.065	0.1	4.0013	0.1	0.05	0.1
WEIR	0.1	0.02	0.1	1.0012	0.1	0.05	0.1
4.03	0.1	0.05	0.1	4.0011	0.1	0.05	0.1
4.02	0.1	0.05	0.1	4.0010	0.1	0.05	0.1
4.01	0.1	0.05	0.1	4.0009	0.1	0.05	0.1
4.0043	0.1	0.05	0.1	4.0008	0.1	0.05	0.1
4.0042	0.1	0.05	0.1	4.0007	0.1	0.05	0.1
4.0041	0.1	0.05	0.1	4.0006	0.1	0.05	0.1
4.0040	0.1	0.05	0.1	4.0005	0.1	0.05	0.1
4.0039	0.1	0.05	0.1	4.0004	0.1	0.05	0.1
4.0038	0.1	0.05	0.1	4.0003	0.1	0.05	0.1
4.0037	0.1	0.05	0.1	4.0002	0.1	0.05	0.1
4.0036	0.1	0.05	0.1	4.0001	0.1	0.05	0.1
4.0035	0.1	0.05	0.1	4	0.025	0.035	0.08
4.0034	0.1	0.05	0.1	3	0.025	0.045	0.025
4.0033	0.1	0.05	0.1	2	0.03	0.035	0.035
4.0032	0.1	0.05	0.1	1	0.07	0.05	0.07
4.0031	0.1	0.05	0.1				

Table 7.3 Original roughness coefficients (Manning's n) used in model set-up to represent degree of friction acting on the flow at each cross section site

7.2.1.4 Sediment

Sediment size distribution data were required as input boundary conditions for the sediment transport component of the model. Sediment profiles were collected at a number of sites (cross sections 12, 5, 4.09, 4.05 and 4.01, Figure 7.3), using Wolman plates to measure the b-axis of 100 clasts (100 clasts is considered a statistically significant sample size and measurement of the b-axis is the standard approach, e.g. Wolman, 1954; Latulippe *et al.*, 2001) from the channel, and sediment extracted from a quadrat to determine the proportion of an area that was finer than fine gravel (8mm) and which was sand or smaller (<2mm) (Latulippe *et al.*, 2001 suggest that a sample area of 1m² is the accepted approach). The sediment profiles are shown in Figure 7.4, which illustrates how sediment size distribution changes around the weir. At the most upstream site (cross section 12, see Fig 7.3), the curve resembles that published by Fuller (2002) for the River Coquet, Northumberland, a river with similar catchment characteristics to the Derwent, in the upper reaches. The profile shows a distribution which includes a wide range of sediment sizes, with fine, coarse and intermediate sizes being roughly evenly represented. Nearer the weir (cross sections 4.09 and 4.05), the high proportion of fine sediment (which accumulates behind the weir as flow loses energy and deposits its load) within a sample is represented by the high and extended starting limb of the curve. This type of profile extends upstream from the weir for about 300m. Downstream of the weir, fine sediment is less dominant, but still present in greater proportions than in the upstream sites (cross sections 12 and 5). Within HEC-RAS, sediment profiles are assigned to each cross section in the model and the five profiles collected were considered appropriate to represent all of the cross sections in which there was interest in sediment dynamics (i.e. between cross sections 4 and 5, with the profiles collected upstream of cross section 5 used to determine the input of sediment to the reach between cross sections 4 and 5).

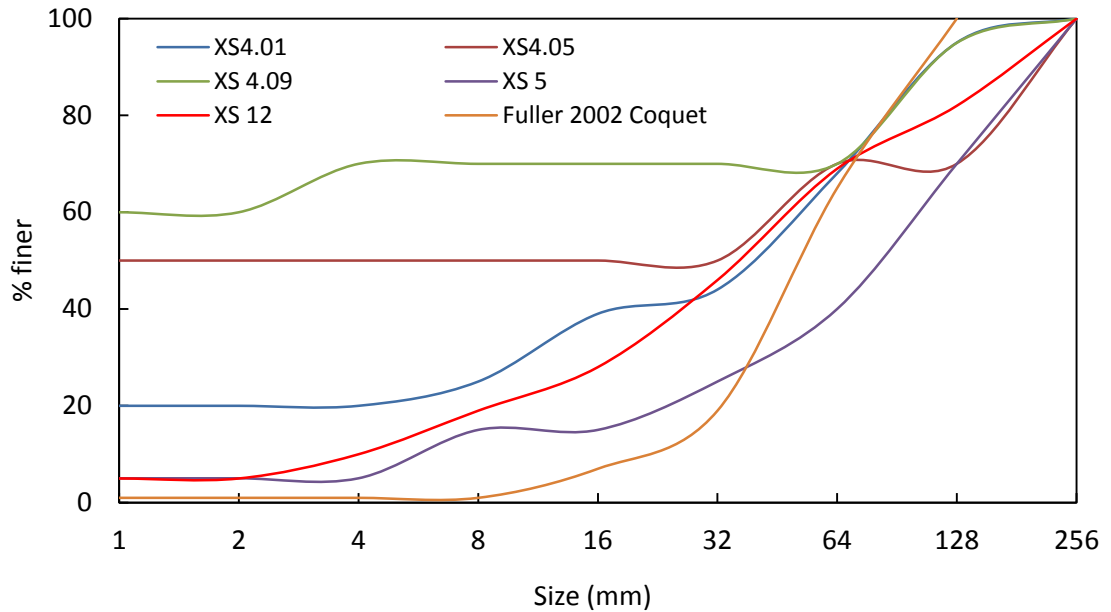


Figure 7.4 Sediment size profiles for a number of sites on the River Derwent, and one on the River Coquet, as published by Fuller (2002). Proportions are presented as percentage of the sample finer than (Wolman, 1954). All cross section locations are illustrated in Figure 7.3

HEC-RAS allows the user to select a sediment transport equation for use in the model. The equations available for selection are; Ackers-White (1973), Engelund-Hansen (1967), Laursen (Copeland) (1958), Meyer-Peter Muller (1948), Toffaleti (1968) and Yang (1973; 1984). Because of the sensitivity of sediment transport models to the specific transport equation applied, users must select carefully the most appropriate equation for the study in question. Therefore, the suitability of each sediment transport equation (available in HEC-RAS) was considered in order to ensure use of the most appropriate function in the sediment modelling component. Table 7.4 details the characteristics, applications and parameters of each function.

A sensitivity analysis was conducted to determine the impact that a number of the formulae have on sediment transport predictions in the model. The results (Figure 7.5) show that there is considerable variation between the different sediment transport formulae and that the Engelund-Hansen formula produced the most extreme changes to the channel cross section. It was decided that for the purposes of this study, the Yang equation (Equation 7.3) would be the most appropriate for a number of reasons. Firstly, the Yang formula is the only one of the options which is designed to account for coarse sediment (gravel) as well as fine sediment (the 1973 version of the transport equation was expanded in 1984 to include gravel-sized sediments), which dominate in this river. Secondly, Yang and Schenggan (1991) state that the Yang formula is the

most accurate formula of eight tested (see Table 7.4) for predicting total bed-material load, when tested with both field and laboratory data and that other formulas, such as Toffaleti (as well as Colby, 1964 and Einstein, 1950) should not be used on small rivers. Stevens and Yang (1989) also showed that the Yang formula out-performs the Engelund and Hansen, Laursen, Colby, Ackers and White, Einstein and Tofaletti formulae when computed sediment transport loads are compared with observed field loads (see Yang and Scheggan 1991 for details, pg 977&982). Finally, Yang and Scheggan (1991) note that the Yang formula is best (of those tested within the paper) at predicting size distribution of sand bed material in transportation.

Sediment transport function	Development/application context	Basis/assumptions	Performance when compared to other sediment transport functions	Mathematical representation, as used in HEC-RAS
Ackers-White (1973)	<ul style="list-style-type: none"> - Developed in terms of particle size, mobility and transport - Applicable to grains up to 7mm, but not below 0.04mm - Flume based - Not applicable to upper phase transport (Froude >0.8) - Optional hiding factor to account for shielding of smaller particles to flow, by larger particles 	<ul style="list-style-type: none"> - Fine sediment transport linked to turbulent fluctuations in water column, coarse transport linked to net grain shear (with V as representative variable) 	<ul style="list-style-type: none"> - Poorest performer for predicting total bed-material load based on field data - Under-predicts total bed material load when compared to measured data (Stevens and Yang, 1989) 	$X = \frac{G_{gr} S d_s}{D \left(\frac{u_*}{V}\right)^n}$ <p style="text-align: center;">and</p> $G_{gr} = C \left(\frac{F_{gr}}{A} - 1\right)$ <p>Where: X = sediment concentration (ppp); G_{gr} = sediment transport parameter; S = specific gravity of sediments; d_s = mean particle diameter; D = effective depth; u_* = shear velocity; V = average channel velocity; n = transition exponent; C = coefficient; F_{gr} = sediment mobility parameter, and A = critical sediment mobility parameter</p>
Engelund-Hansen (1967)	<ul style="list-style-type: none"> - Total load predictions - Flume based - Tested on sediment sizes ranging between 0.19 and 0.93mm - Good predictions for sandy rivers with substantial suspended load - Extensively tested and found to be relatively consistent with field data 		<ul style="list-style-type: none"> - Ranked second (of 8) for accuracy in predicting total bed-material load, based on laboratory data, and third (of 8) for predicting total bed-material load based on field data - Over-predicts total bed load when compared to measured data (Stevens and Yang, 1989) 	$g_s = 0.05 \gamma_s V^2 \sqrt{\frac{d_{50}}{g \left(\frac{\gamma_s}{\gamma} - 1\right) \left[\frac{\tau_o}{(\gamma_s - \gamma) d_{50}}\right]^{3/2}}}$ <p>Where: g_s = unit sediment transport (kg/m); γ = unit weight of water; γ_s = unit weight of solid particles; V = average channel velocity; τ_o = bed level shear stress; d_{50} = particle size of which 50% is smaller</p>

Laursen (1958)

- Total load predictions
 - Based on qualitative analysis, original experiments and supplementary data
 - Applicable to gravel sized sediment (through extension by Copeland & Thomas, 1989)
 -Applicability to sediment size 0.011-29mm

- Transport rate is linked to channel V, D, S, gradation and fall velocity (of sediment)

- Ranked fourth (of 8) for accuracy in predicting total bed-material load, based on laboratory data, and sixth (of 8) for predicting total bed-material load based on field data
 - Under-predicts total bed material load when compared to measured data (Stevens and Yang, 1989)

$$C_m = 0.01\gamma \left(\frac{d_s}{D}\right)^{7/6} \left(\frac{\tau'_o}{\tau_c} - 1\right) f\left(\frac{u_*}{\omega}\right)$$

Where: C_m = sediment discharge concentration (in weight/volume); G = unit weight of water; d_s = mean particle diameter; D = effective depth of flow; τ'_o = bed shear stress due to grain resistance; τ_c = critical bed shear stress; $f\left(\frac{u_*}{\omega}\right)$ = function of the ratio of shear velocity to fall velocity, as defined in Laursen's Figure 14 (Laursen, 1958)

Meyer-Peter Müller (1948)

- Based on experimental data
 -Extensively tested and used for fairly coarse sediment rivers
 -Applicable to sediment sizes 0.4 – 29mm
 - Can be used for well-graded sediments and flow conditions that produce other-than-plane bed forms

- Transport rate is proportional to difference between mean shear stress on grain, and critical shear stress
 -Darcy-Weisbach factor used to define bed resistance
 - Results may be questionable near threshold of incipient motion for sand bed channels (Amin and Murphy, 1981)

- Not useful for sand bed channels at or near incipient (starting) motion (Amin and Murphy, 1981)

$$\left(\frac{k_r}{k'_r}\right)^{3/2} \gamma RS = 0.047(\gamma_S - \gamma)d_m + 0.25 \left(\frac{\gamma}{g}\right)^{1/3} \left(\frac{\gamma_S - \gamma}{\gamma_S}\right)^{2/3} g_S^{2/3}$$

Where: g_s = unit sediment transport weight (in weight/time/unit width); k_r = a roughness coefficient; k'_r = a roughness coefficient based on grains; γ = unit weight of water; γ_S = unit weight of the sediment; g = acceleration of gravity; d_m = median particle diameter; R = hydraulic radius; S = energy gradient

Toffaletti (1968)	<ul style="list-style-type: none"> - Modified-Einstein total load function - Based on flume and field data - Tested on particles 0.3 - 0.93mm 	<ul style="list-style-type: none"> - Breaks suspended load distribution into 4 vertical zones (upper, middle, lower, bed), replicating 2D sediment movement - Sum of 4 zones = total load 	<ul style="list-style-type: none"> - Potentially unsuitable for flume and small river application - Poorest performer for predicting total bed-material load based on laboratory data, but second best for field data - Under-predicts total bed material load when compared to measured data (Stevens and Yang, 1989)
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$$g_{ssL} = M \frac{\left(\frac{R}{11.24}\right)^{1+n_v-0.756z} - (2d_m)^{1+n_v-0.756z}}{1+n_v-0.756z}$$

(lower zone)

$$g_{ssM} = M \frac{\left(\frac{R}{11.24}\right)^{0.244z} \left[\left(\frac{R}{2.5}\right)^{1+n_v-z} - \left(\frac{R}{11.24}\right)^{1+n_v-z} \right]}{1+n_v-z}$$

(middle zone)

$$g_{ssU} = M \frac{\left(\frac{R}{11.24}\right)^{0.244z} \left(\frac{R}{2.5}\right)^{0.5z} \left[R^{1+n_v-1.5z} - \left(\frac{R}{2.5}\right)^{1+n_v-1.5z} \right]}{1+n_v-1.5z}$$

(upper zone)

$$g_{sb} = M(2d_m)^{1+n_v-0.756z}$$

(bed zone)

$$M = 43.2C_L(1+n_v)VR^{0.756z-n_v}$$

$$g_s = g_{ssL} + g_{ssM} + g_{ssU} + g_{sb}$$

Where: g_{ssL} ; g_{ssM} ; g_{ssU} = suspended sediment transport in the lower, middle and upper zones, respectively (in tons/day/ft); g_{sb} = bed load sediment transport; g_s = total sediment transport; M = sediment concentration parameter; C_L = sediment concentration in the lower zone; R = hydraulic radius; d_m = mean particle diameter; z = exponent describing relationship between sediment and hydraulic characteristics; n_v = temperature exponent

Yang (1973; 1984)	- Based on flume and field data from wide range of conditions in alluvial channels - Sediment size application ranges between 0.062 – 7.0mm - Expanded (Yang, 1984) to include gravel sized sediment	- Premise that unit stream power = dominant control on total sediment concentration	- Most accurate formula for predicting total bed-material load based on both laboratory and field data sets - Conclude that the Yang formula is most efficient at accurately predicting size distribution of bed materials in transport - Computed results matched measured data very well, for a sediment gauge on Niobrara River (Stevens and Yang, 1989)	$\log C_t = 5.435 - 0.286 \log \frac{\omega d_m}{\nu} - 0.457 \log \frac{u_*}{\omega} + \left(1.799 - 0.409 \log \frac{\omega d_m}{\nu} - 0.314 \log \frac{u_*}{\omega} \right) \log \left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right)$ <p>For sand ($d_m < 2\text{mm}$)</p> $\log C_t = 6.681 - 0.633 \log \frac{\omega d_m}{\nu} - 4.816 \log \frac{u_*}{\omega} + \left(2.784 - 0.305 \log \frac{\omega d_m}{\nu} - 0.282 \log \frac{u_*}{\omega} \right) \log \left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right)$ <p>For gravel ($d_m > 2\text{mm}$)</p>
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Where: C_t = total sediment concentration (ppm); ω = particle fall velocity; d_m = median particle diameter; ν = kinematic viscosity; u^* = shear velocity; V = average channel velocity; S = energy gradient

Table 7.4 Selection of sediment transport functions available within the sediment transport component of HEC-RAS (After HEC-RAS Reference Manual, US Army Corps of Engineers, 2010b). Table summarises the assumptions and details upon which the formulas were developed, the basis of the formulas, their relative accuracy when compared with others, and the equations/parameters by which they are calculated. For notes on performance when compared to other sediment transport functions, comments made are based on those presented by Yang and Schenggan (1991), unless otherwise stated. Within their analysis, the eight formulas compared by Yang and Schenggan (1991) include Ackers-White (d_{50} and d_{35} ; 1973); Colby (1964); Einstein (1950) Engelund and Hansen (1967); Laursen (1958); Toffaleti (1968), and Yang (1973)

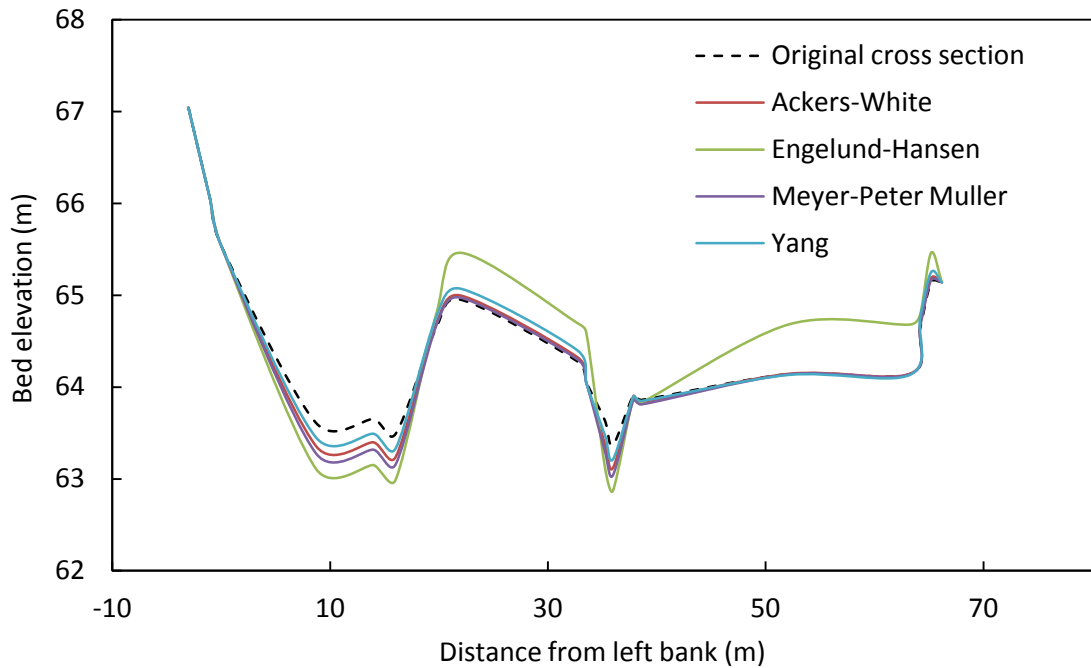


Figure 7.5 Cross section change (XS 4.03) in response to different sediment transport equations used within the HEC-RAS sediment transport component

In HEC-RAS, flow in sediment transport calculations must be represented at the upstream external boundary as a *flow series*. This consists of a number of time-steps of varying duration, with a constant flow *rate* within any one time-step. A computational increment is also assigned to each flow time-step, this dictates the frequency with which the hydrodynamics (backwater computations) are computed and the bathymetry updated, for example, a computation interval of 1 would perform the backwater computations once for every hour of the duration of that time-step. This allows the model to calculate sediment changes more frequently at peak flows (when most sediment transport occurs) and less frequently in low flows, to make most efficient use of computation time. For this study, the impact of changes to the channel over a time period of a number of months was required. Therefore, a flow series for one year was prepared and applied to the model. Time steps in the flow series were set to cover a flow range of $0.1\text{m}^3\text{s}^{-1}$ (e.g. for as long as flow rates were between 0.40 and $0.49\text{m}^3\text{s}^{-1}$, this was considered as one time-step. When the flow reached $0.5\text{m}^3\text{s}^{-1}$, a new flow time-step was started). The computation increment was set as 1 hour for all flows exceeding $1\text{m}^3\text{s}^{-1}$, and 12 hours for all flows below $1\text{m}^3\text{s}^{-1}$. In initial trials, the lowest computation increment was set at 0.1 hours with a more detailed gradation up to 12 hours. However, this produced data files so large that it caused the program to crash and calculations could not be completed, therefore, the computation intervals had to be simplified so that a computation interval of 0.1 was reserved for the highest peak of the year. To represent

tributary inflows, a lateral flow series can be applied to each cross section. These were calculated in the same way that the lateral inflows were calculated for the regular flow time series (see Section 7.2.1.1).

7.2.2 Parameterisation of the flow model component

Once the flow prediction component of the model had been set up for the study river with boundary conditions (hydrology and topography data), and environmental conditions (starting flow and roughness values), the model was run with the chosen hydrograph. The output hydrograph was compared to the observed hydrograph at the output boundary and, as expected, the two data sets were somewhat different (Figure 7.6). At this point, roughness coefficients for the channel and banks were altered systematically to determine their influence on the hydrograph and subsequently, n values were changed in order to achieve the best agreement between hydrographs and the best goodness-of-fit results possible. The results of the calibration steps are shown in Figures 7.7 and 7.8. Figure 7.7 shows how roughness coefficients were first altered to improve the *timing* of the predicted peak (step one). Roughness was first increased just upstream of the weir to determine whether a pooling of water behind the weir would cause flow to reach the output boundary more gradually. This had a limited impact, so the principle was extended to the whole stretch of river downstream of the weir, which had a more pronounced impact on the timing of the peak. Extending the number of cross sections with a high roughness coefficient (0.09) upstream after cross section 5 had negligible impact in delaying the peak. While using a Manning's n value of 0.13 produced the closest time of peak when compared to the observed peak, the US Army Corps of Engineers, (2010a) warns against increasing roughness parameters to unrealistic levels solely to force one hydrograph to match another, as the result will most likely be incorrect calculation of flow. Figure 7.7 illustrates how the higher roughness coefficients, particularly when assigned to the most downstream cross sections, cause a delay in the peak flow, allowing the modelled hydrograph to more closely represent the observed hydrograph. However, as conveyance is reduced through increased friction, the height of the peak begins to diminish, as can be seen in Figure 7.8, most noticeably when the very high (and unrealistic) Manning's n value of 0.13 was applied to the whole channel. Therefore, rather than suggest an optimum Manning's n value at this stage, the apparent efficiency of a high n value downstream was noted when aiming to calibrate the whole hydrograph for magnitude of peak.

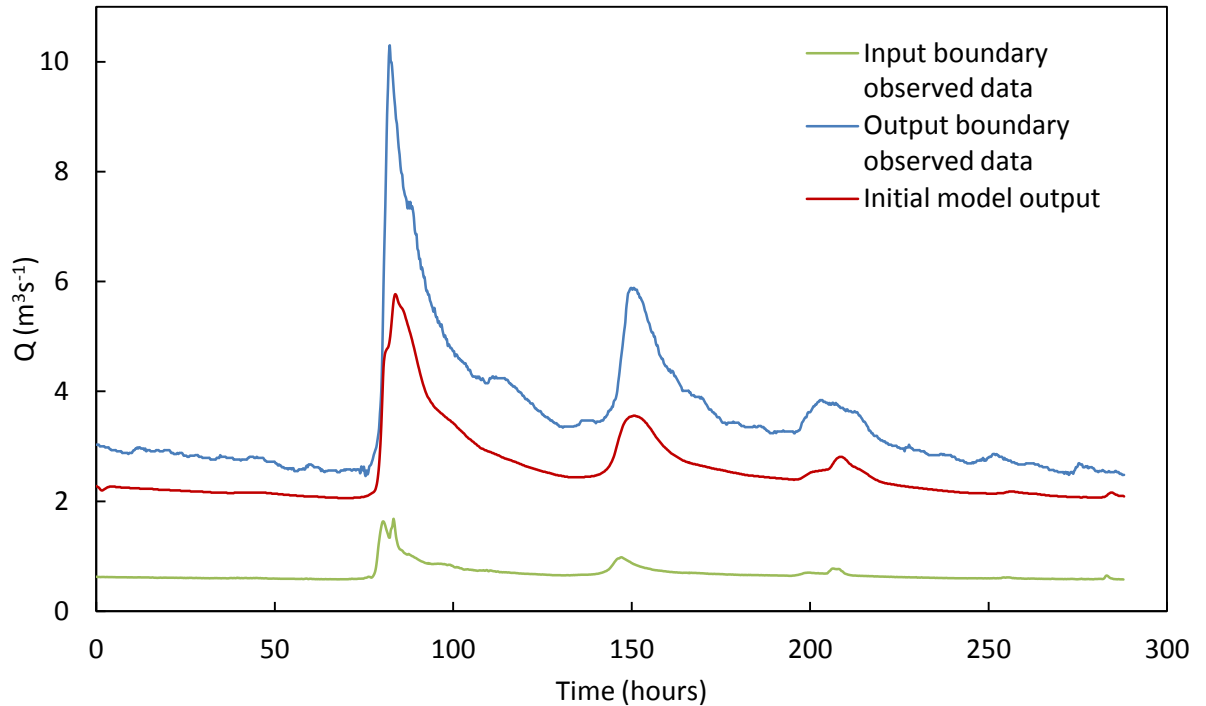


Figure 7.6 Observed data used for the input and output boundary conditions in HEC-RAS, and the initial model output before calibration. Timing of peaks is relatively well predicted, but magnitude is somewhat too low

As a result of the above finding, focus for the next step in calibration (step two) was placed on the cross sections downstream of the weir (cross sections 1-4). Manning's n values were altered to try to improve the magnitude of the predicted hydrograph. It is evident from Figure 7.8 and Table 7.5 that altering roughness values on the most downstream cross sections had a limited impact on magnitude of peak predictions. Therefore the *ratio* of roughness between the downstream and upstream reaches was varied by maintaining a high roughness value for cross section 1 and changing the Manning's n value for the rest of the channel (see Figure 7.8). This was more effective and improved many of the objective functions slightly (Table 7.6), although the most noticeable improvement was in the magnitude of the predicted peak when n at cross section 1 was 0.08 and n for the rest of the channel was 0.015. This combination of roughness coefficient values allowed the water to be moved through most of the channel quickly, but slowed upon reaching the output boundary. Under (or over) estimation of peak flows is a common problem in hydraulic modelling and US Army Corps of Engineers (2010a) suggests that users should expect error in the range of 10% of flow, or 0.15m in stage. While the error in peak for most predictions lies between 20 and 30 per cent, the percentage error in mean for the optimum set of n values is 4.47% (underestimation). Furthermore, the Nash and Sutcliffe coefficient (0.87) and the RMSE ($\pm 0.42\text{m}^3\text{s}^{-1}$) values are both within the acceptable range, as cited by Shrestha *et al.* (2007), Wu

and Johnstone (2008) and Gumindoga *et al.* (2011) (see Chapter Six for a discussion of the use of various objective functions in hydraulic modelling). Therefore, the model performance was considered accurate enough to progress to the benchmarking and evaluation stages (where the suitability of the model would be further tested before it would be used in application).

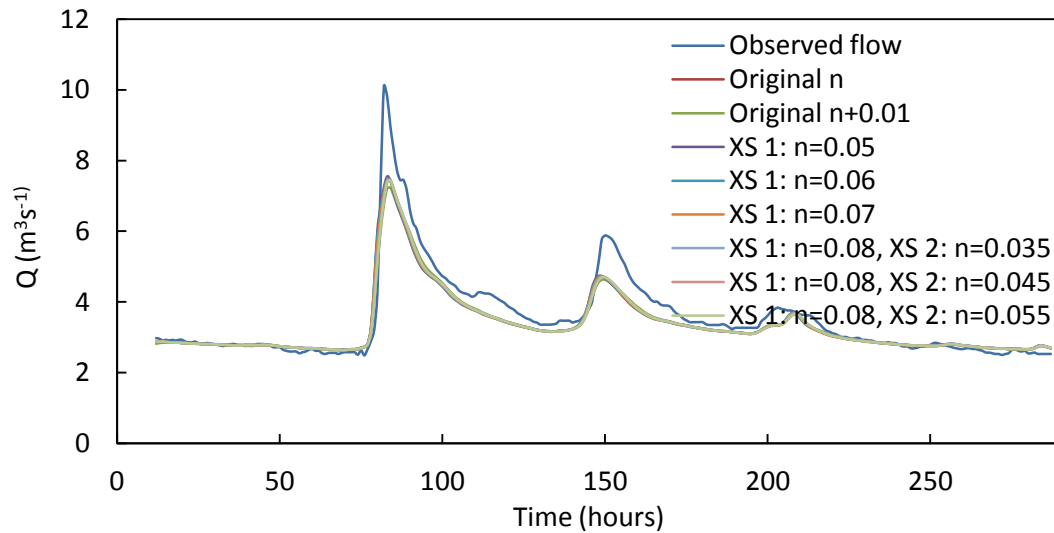


Figure 7.7 Hydrograph prediction for step one of the calibration process depicting model response to the change in roughness parameters in varying combinations at different cross sections

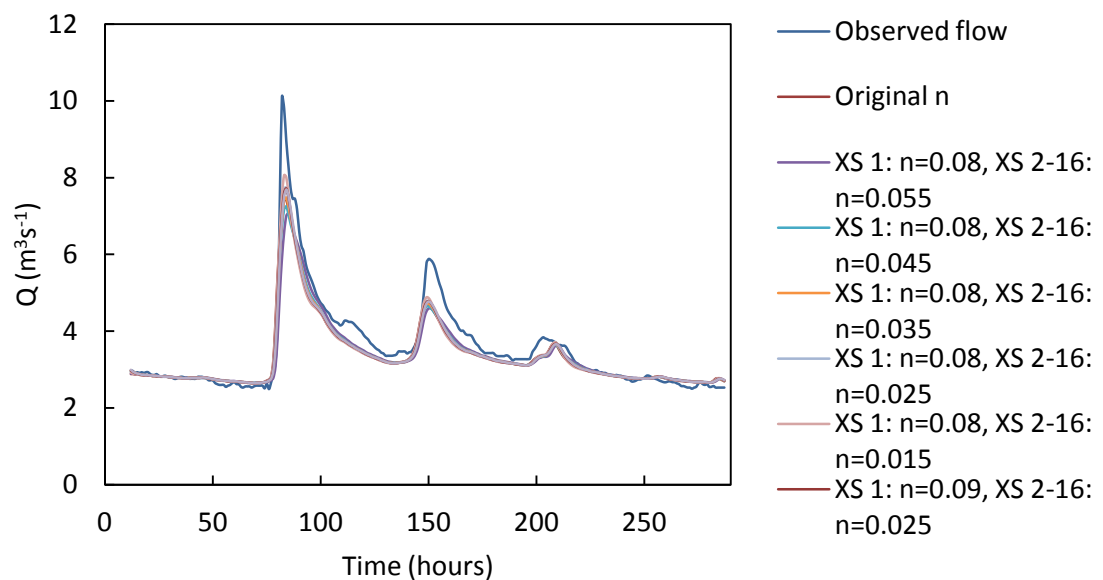


Figure 7.8 Hydrograph prediction for step two of the calibration process depicting model response to the change in roughness parameters, with a focus on cross sections upstream of the output boundary.

Objective function	Original n	Original n+0.01	XS1: n=0.05	XS1: n=0.06	XS1: n=0.07	XS1: n=0.08, XS2: n=0.035	XS1: n=0.08, XS2: n=0.045	XS1: n=0.08, XS2: n=0.055
NS	0.87	0.86	0.86	0.86	0.87	0.87	0.87	0.87
RMSE	0.43	0.44	0.44	0.44	0.43	0.42	0.42	0.42
MD	0.18	0.19	0.17	0.17	0.18	0.18	0.18	0.18
%EM	-5.22	-5.4	-5.02	-5.09	-5.16	-5.28	-5.33	-5.33
%ETP	1.2	2.4	1.2	1.2	1.2	2.4	1.2	1.2
%EP	-26.43	-28.41	-25.24	-25.74	-26.23	-26.33	-26.33	-26.33
R ²	0.95	0.95	0.93	0.94	0.94	0.95	0.96	0.96

Table 7.5 Objective function results for step one of the calibration process, including the following goodness of fit statistics: NS (Nash and Sutcliffe, 1970); RMSE (Root mean square error, Patry and Marino, 1983); MD (mean deviation, Green and Stephenson, 1986); %EM (Percentage error in mean, Green and Stephenson, 1986); %ETP (Percentage error in timing of peak); %EP (Percentage error in peak), and R². Statistical tests were chosen based on the appropriateness for this case (see Table 6.1 for evaluation of tests, and related formulae, for the more complex analyses).

Objective function	Original n	XS1: n=0.08, XS2-16: n=0.055	XS1: n=0.08, XS2-16: n=0.045	XS1: n=0.08, XS2-16: n=0.035	XS1: n=0.08, XS2-16: n=0.025	XS1: n=0.08, XS2-16: n=0.015	XS1: n=0.09, XS2-16: n=0.025	XS1: n=0.1, XS2-16: n=0.025
NS	0.87	0.86	0.87	0.87	0.87	0.87	0.88	0.88
RMSE	0.43	0.45	0.43	0.42	0.42	0.42	0.41	0.41
MD	0.18	0.18	0.17	0.17	0.16	0.15	0.16	0.17
%EM	-5.22	-5.19	-5.02	-4.85	-4.66	-4.47	-4.77	-4.86
%ETP	1.2	2.4	2.4	2.4	2.4	1.2	2.4	2.4
%EP	-26.43	-30	-28.21	-25.94	-23.36	-20.19	-23.56	-23.86
R ²	0.95	0.95	0.97	0.96	0.95	0.93	0.95	0.95

Table 7.6 Objective function results for step two of the calibration process, including the following goodness of fit statistics: NS (Nash and Sutcliffe, 1970); RMSE (Root mean square error, Patry and Marino, 1983); MD (mean deviation, Green and Stephenson, 1986); %EM (Percentage error in mean, Green and Stephenson, 1986); %ETP (Percentage error in timing of peak); %EP (Percentage error in peak), and R²

7.2.3 Benchmarking

The process of benchmarking (also referred to as verification), is used to determine how sensitive a model is to changes in resolution, such as spatial and temporal resolution of the model. In theory, a model suitable for application should solve the hydraulic equations in the same way, regardless of computational time-step or cross section spacing (i.e. it should be temporally and spatially discretisation independent). In reality, there will be some variation in modelled outputs when the resolution is very low, but model accuracy should increase with resolution, until a window of convergence is reached, in which there is little improvement in prediction accuracy, despite increasing resolution. For this study, the impact of varying computational time-steps and cross section spacing was examined. The calibrated version of the model (see Section 7.2.2) was run a number of times, and each time only the computational time-step *or* cross section spacing was changed. The range of values applied for both the temporal and spatial tests were designed to include levels of resolution which would be computationally demanding but may produce more accurate results (e.g. high resolution: 1 second time-steps, or 3m cross section spacing), and those which might be more computationally efficient, but may produce less accurate predictions (e.g. low resolution: 1 day time-steps or 200m cross section spacing), see Table 7.7. The predicted hydrographs and the objective function results for each simulation were used to assess the degree of model sensitivity.

Range of computational time-steps (5m cross section spacing used in all simulations)	Range of cross section spacing (15 minute computational time-step used in all simulations)
1 day	200m
1 hour	100m
12 hours	50m
4 hours	20m
2 hours	10m
1 hour	5m
30 minutes	3m
15 minutes	
10 minutes	
5 minutes	
1 minute	
1 second	

Table 7.7 Range of temporal and spatial iterations applied to calibrated model during sensitivity analysis

Figure 7.9 and Table 7.8 illustrate the range of predictions that resulted from varying computational time-steps. A time-step of one day caused the peak flow predictions to be both delayed in time and significantly underestimated. Predictions at low flows were generally

acceptable. At the 12 hour time-step, there was also some delay in timing, and underestimation of peak magnitude, although it was more accurate than the 1 day time-step. At any resolution greater than 12 hours, the model performance was fairly consistent, as can be seen in Figure 7.9, it is difficult to distinguish between any of the hydrographs for time-steps between 4 hours and 1 second. Table 7.8 shows that there are small improvements in accuracy of predictions as resolution increases, with the 1 second time-step producing the best range of statistics overall (such as a Nash-Sutcliffe score of 0.89 and a RMSE of $\pm 0.4 \text{ m}^3 \text{ s}^{-1}$). However, many of the objective function scores had only minimal accuracy improvements, at the expense of very long computational processing times (the simulation with a 1 hour time-step took 8 minutes, while the 1 second time-step lasted 3 hours). This convergence is illustrated in Figure 7.11, in which there is stability in the model's predictive ability, until model resolution drops below one (hour). The exception here is when considering percentage error in peak flow, which is somewhat unstable until the model resolution reaches 0.01 hours (1 minute). However, the model never achieves a high degree of accuracy in prediction of peak magnitude. When applying the model as a research tool, the user must decide upon the optimum balance of accuracy and computational effort. In this case, the prediction accuracy of the 1 hour time-step was considered to be as acceptable as that of the 1 second time-step, with the caution that peak flows are always underestimated.

The model was much less sensitive to spatial discretisation and cross section spacing of any degree between 3m and 200m produced consistent hydrograph predictions (Figure 7.10). As Table 7.9 shows, there were negligible changes in the objective function results for the range of cross section spaces, with the exception of the RMSE, which decreased as model resolution increased (from $\pm 3.99 \text{ m}^3 \text{ s}^{-1}$ to $\pm 0.82 \text{ m}^3 \text{ s}^{-1}$). Figure 7.12 shows that there is little variation in accuracy even for the lowest resolution, and that the 'window of convergence' effectively exists across all resolutions. Therefore, the model is considered to be spatially discretisation independent. This means that it can be applied with an efficient computation time of around 6 minutes, when both the optimum time-step (1 hour) and optimum cross sectional spacing (100m) are applied to a 19 day simulation.

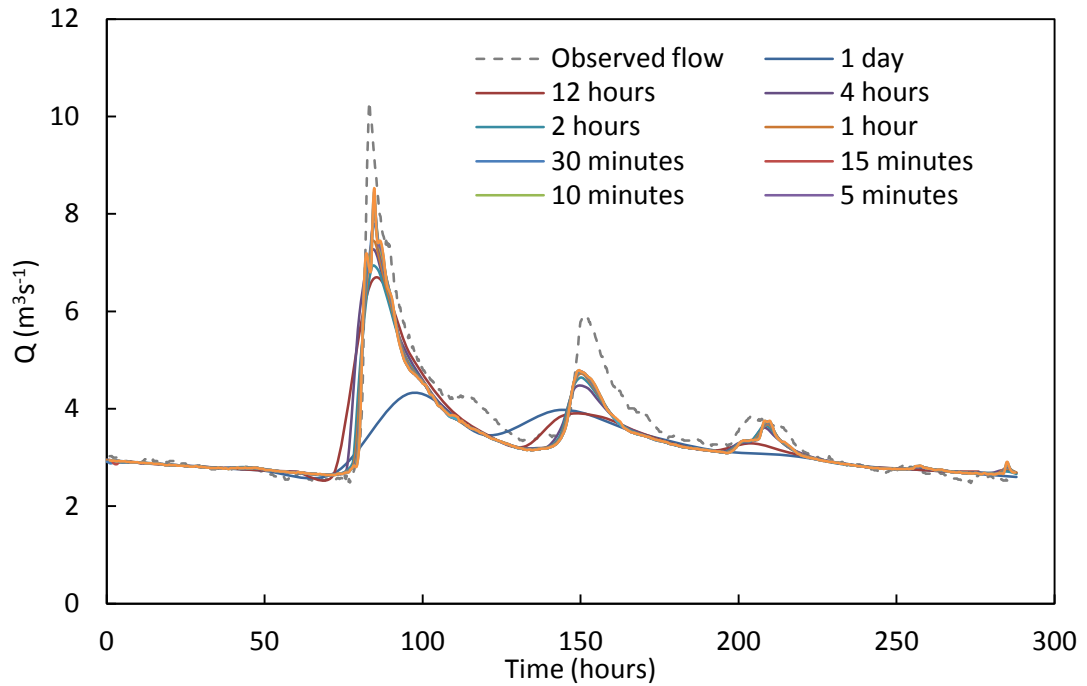


Figure 7.9 Hydrograph prediction performance under varying computation time-steps, ranging from time-steps of 1 second to 12 hours. Larger time-steps result in poorer predictions

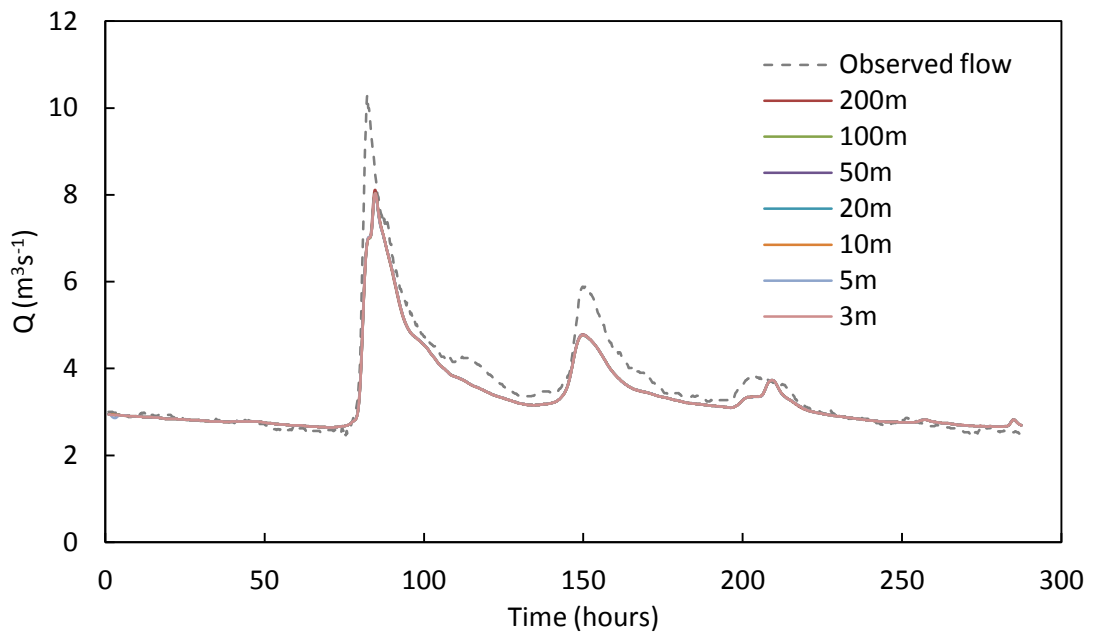


Figure 7.10 Hydrograph prediction performance under varying cross sectional spacing, ranging from a maximum distance of 3m between cross sections, to a maximum of 200m between cross sections. Cross sectional spacing has limited impact on model efficiency, demonstrated by the seven identical output hydrographs in this figure

Objective function	1 d	12 h	4 h	2 h	1 h	30 m	15 m	10 m	5 m	1 m	1 s
NS	0.79	0.17	0.79	0.85	0.87	0.88	0.88	0.89	0.89	0.89	0.89
RMSE	0.36	1.4	0.55	0.46	0.43	0.41	0.41	0.40	0.40	0.40	0.40
MD	0.14	0.24	0.16	0.19	0.18	0.18	0.19	0.18	0.18	0.18	0.18
%EM	-4.11	-6.47	-4.48	-5.36	-5.22	-5.20	-5.17	-5.20	-5.20	-5.20	-5.15
%ETP	0	-12.5	0	0	1.2	1.8	1.8	1.5	1.8	1.8	1.8
%EP	-18.2	-32.4	-26	-29.5	-26.3	-22.8	-22.1	-21.7	-19.6	-17.9	-17.2
R ²	0.88	0.21	0.83	0.94	0.95	0.96	0.96	0.96	0.96	0.95	0.95

Table 7.8 Objective function results for computation time-step sensitivity analysis, including the following goodness of fit statistics: NS (Nash and Sutcliffe, 1970); RMSE (Root mean square error, Patry and Marino, 1983); MD (mean deviation, Green and Stephenson, 1986); %EM (Percentage error in mean, Green and Stephenson, 1986); %ETP (Percentage error in timing of peak); %EP (Percentage error in peak), and R²

Objective function	200m	100m	50m	20m	10m	5m	3m
NS	0.88	0.88	0.92	0.88	0.88	0.88	0.88
RMSE	3.99	2.90	2.01	1.65	1.16	0.82	0.82
MD	0.18	0.18	0.18	0.18	0.18	0.18	0.18
%EM	-5.16	-5.16	-5.16	-5.16	-5.16	-5.17	-5.16
%ETP	3.04	3.34	3.04	3.04	3.04	3.04	3.04
%EP	-21.3	-21.9	-21.9	-21.9	-21.9	-22.1	-21.9
R ²	0.95	0.95	0.95	0.95	0.95	0.95	0.95

Table 7.9 Objective function results for cross section spacing sensitivity analysis, including the following goodness of fit statistics: NS (Nash and Sutcliffe, 1970); RMSE (Root mean square error, Patry and Marino, 1983); MD (mean deviation, Green and Stephenson, 1986); %EM (Percentage error in mean, Green and Stephenson, 1986); %ETP (Percentage error in timing of peak); %EP (Percentage error in peak), and R²

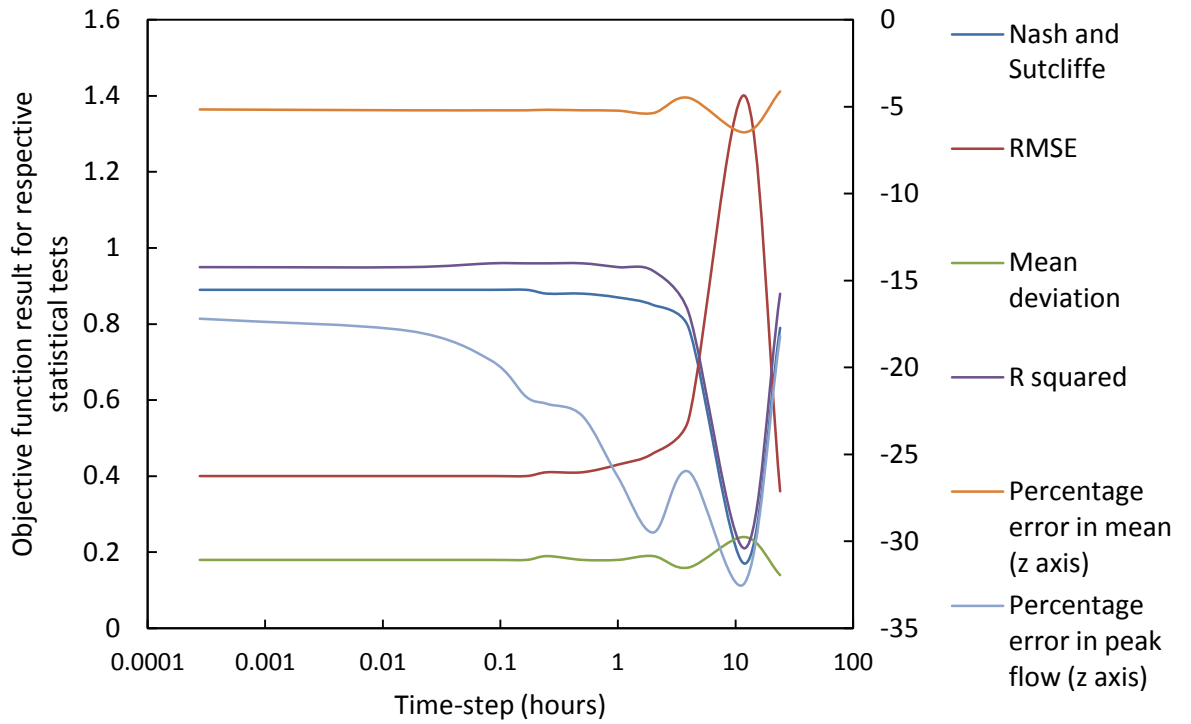


Figure 7.11 Objective function results for computation time-step sensitivity analysis. Nash and Sutcliffe, RMSE, Mean Deviation and R^2 shown on y-axis, Percentage error in mean and percentage error in peak on z-axis

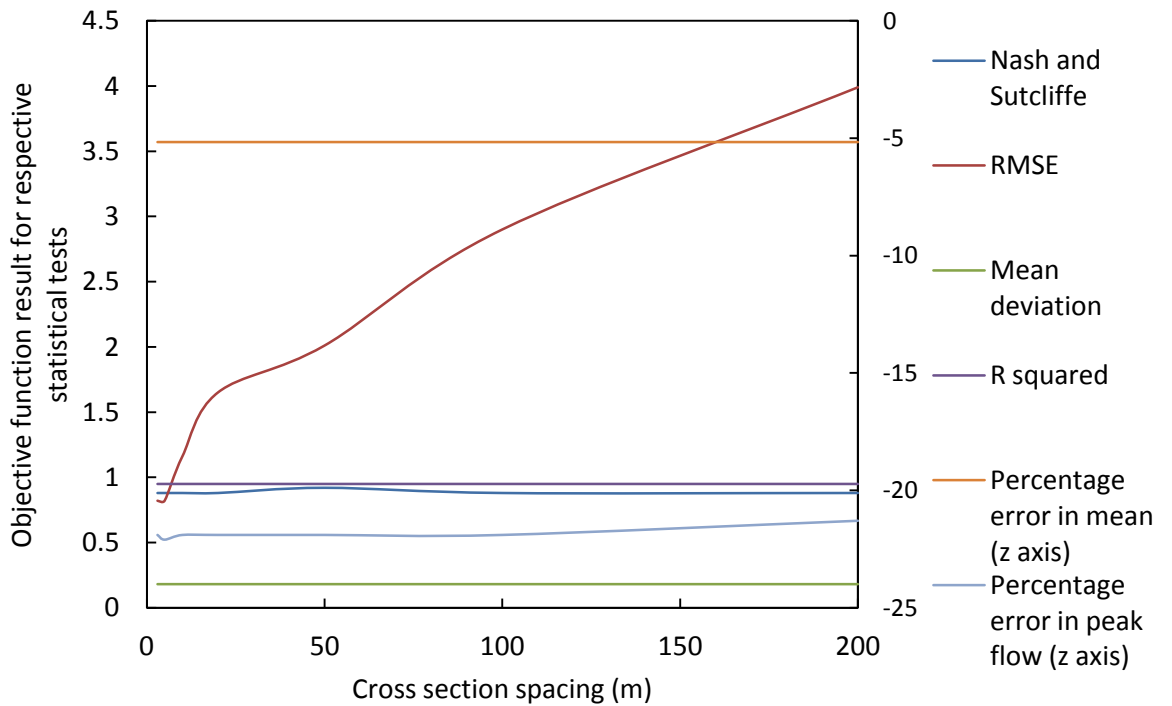


Figure 7.12 Objective function results for cross section spacing sensitivity analysis. Nash and Sutcliffe, RMSE, Mean Deviation and R^2 shown on y-axis, Percentage error in mean and percentage error in peak on z-axis

7.2.4 Evaluation

The final step in model development, before the model can be used in application, is evaluation (or 'validation'). In this step, split sample data are used to test the model's ability to predict flow, based on data to which it has not been calibrated. Two separate hydrographs (EHG1 and EHG2) were chosen from the available data, ensuring that a range of low and high flows were represented in both. Two different hydrographs were chosen to ensure that reasonably accurate predictions could be produced for both, this reduces the likelihood of the model being accepted on the basis of good prediction of a single hydrograph, which may occur by chance. The model performance for each new data set is illustrated in Figures 7.13 and 7.14. For both sets of flow data, the model predicts low flows with some accuracy, but, as with the original calibrated data set, struggles to reproduce the magnitude of the largest peaks. Timing of the peak flows appears to be reasonably accurate, according to Figures 7.13 and 7.14, and this is supported by the percentage error in timing of peak, 0.74% and -0.29% for EHG1 and EHG2, respectively (Table 7.10). EHG1 achieves a Nash and Sutcliffe score of 0.79, which is well within the acceptable range (see Shrestha *et al.*, 2007; Wu and Johnstone, 2008; Gumindoga *et al.*, 2011), while HG2 falls just inside the acceptable range with a Nash and Sutcliffe score of 0.6. When considering RMSE, EHG2 outperforms both EHG1 and the originally calibrated hydrograph, with a value of $\pm 0.26 \text{ m}^3 \text{ s}^{-1}$. Overall performance for the originally calibrated hydrograph, and EHG2 is good, with errors in mean of -0.85% and -2.72%, respectively, while EHG1 is just acceptable (based on guidelines suggested by the US Army Corps of Engineers (2010a), with a percentage error in mean of -10.9. Although the evaluation hydrographs generally do not achieve objective function scores as strong as those of the calibrated hydrograph, they do mostly fall within acceptable ranges (Shrestha *et al.*, 2007; Wu and Johnstone, 2008; Gumindoga *et al.*, 2011) and therefore the model is considered appropriate for application to the questions of the Competence group. As mentioned, the model consistently underestimates the magnitude of the highest peaks. While a certain amount of error is expected when predicting peaks, the errors in this case can be large and so this must be considered when applying the model to questions involving the highest flows.

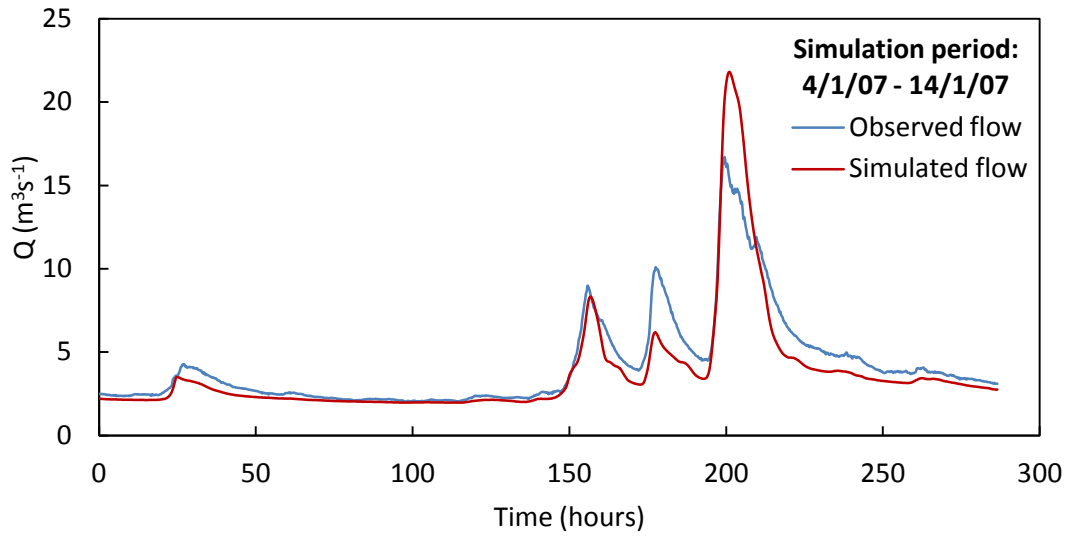


Figure 7.13 Evaluation hydrograph 1: model performance for hydrograph based on data for 4-14th January 2007

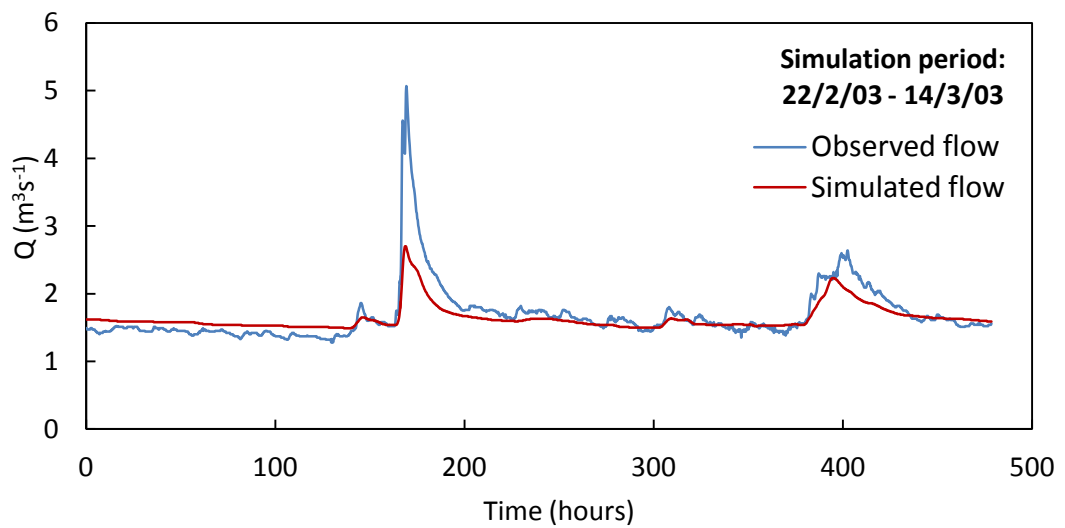


Figure 7.14 Evaluation hydrograph 2: model performance for hydrograph based on data for 22nd February to 14th March 2003

Objective function	Original HG for calibration	Evaluation HG 1 (Jan 2007)	Evaluation HG 2 (Feb-Mar 2003)
NS	0.90	0.79	0.60
RMSE	0.37	1.27	0.26
MD	0.02	0.46	0.05
%EM	-0.85	-10.9	-2.72
%ETP	1.8	0.74	-0.29
%EP	-22.13	30.6	-46.7
R ²	0.96	0.88	0.88

Table 7.10 Objective function results for final calibrated hydrograph and evaluation hydrographs 1 and 2, including the following goodness of fit statistics: NS (Nash and Sutcliffe, 1970); RMSE (Root mean square error, Patry and Marino, 1983); MD (mean deviation, Green and Stephenson, 1986); %EM (Percentage error in mean, Green and Stephenson, 1986); %ETP (Percentage error in timing of peak); %EP (Percentage error in peak), and R²

7.3 Model application

The initial questions raised by the competence group, as discussed in Section 5.5 were based around the impact that a new weir profile would have on the surrounding channel and riparian area. The group's concerns were organised into three research questions:

- What would be the impact of a new weir form on the **water level** behind the weir? Would this increase the capacity for using the pool for boating purposes?
- Would the new weir profile affect **sediment accumulation** both upstream and downstream of the weir? Would this affect the habitat conditions for fish and macroinvertebrates?
- How would the **removal of dense vegetation** from the central bar affect water movement through the reach?

In agreeing to investigate the potential implications of weir restoration on the river at Ebchester, it was made clear to the group that there was no guarantee that the results would bring about changes to the river. Furthermore, the aim of this approach was to create a new knowledge jointly within the group, in order to increase levels of confidence and understanding and that this new social positioning of the group could be the tool through which the group could pursue their cause. The model results in isolation were not designed as a lobbying tool and were not the intended product of the overall project. Rather, they were a means to achieving a deeper understanding and social entity.

As discussed in Section 7.1, HEC-RAS was chosen to investigate these questions using the hydraulic and sediment transport components. The profile for the original weir (Figure 7.15) was based on dGPS measurements taken as part of the geometric data collection. The profile for the restored weir was first based on an assumption of the new shape following CG1 and discussion between the members of what would be required in the weir restoration (i.e. which sections would be restored, where a fish pass would be located, and dimensions of the fish pass). A third, hypothetical profile of a 'degraded weir' was developed, based on the profile of the current weir and expectations of how the weir may continue to deteriorate, should it not be repaired. How each of the questions were addressed is outlined below and results are presented and discussed in the respective sections.

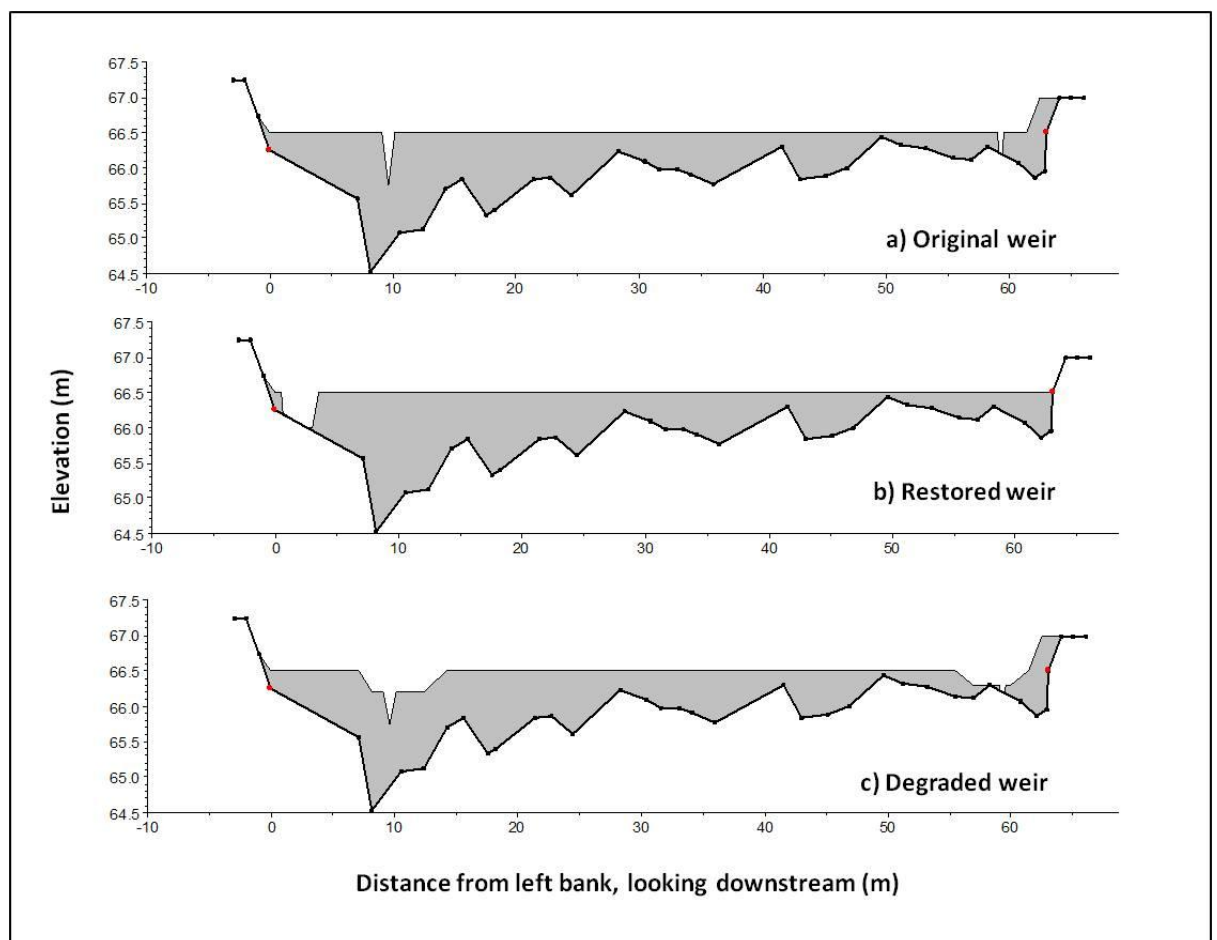


Figure 7.15 Weir profiles used in initial model application: a) original weir profile (based on dGPS data); b) hypothetically restored weir profile; c) hypothetically degraded weir profile.

7.3.1 Water level

To assess the impact of different weir profiles on the water level behind the weir, each profile was applied to the model in turn, and the model was run with the original calibrated hydrograph,

which contains a range of both low and high flow rates, as recommended by US Army Corps of Engineers (2010a). The predicted water levels at cross section 4.04 (the cross section closest to the upstream side of the weir) for each scenario were compared as a time series (Figure 7.16). Change in weir profile appears to impact the water surface elevation. The original weir causes the highest stage, which is less flashy over the duration of the simulation, than the restored and degraded profiles. The lowest stage is produced by the degraded weir, as a result of the increase in area of gap in the weir profile. However, the impact on the overall discharge under the different scenarios was limited (Figure 7.17).

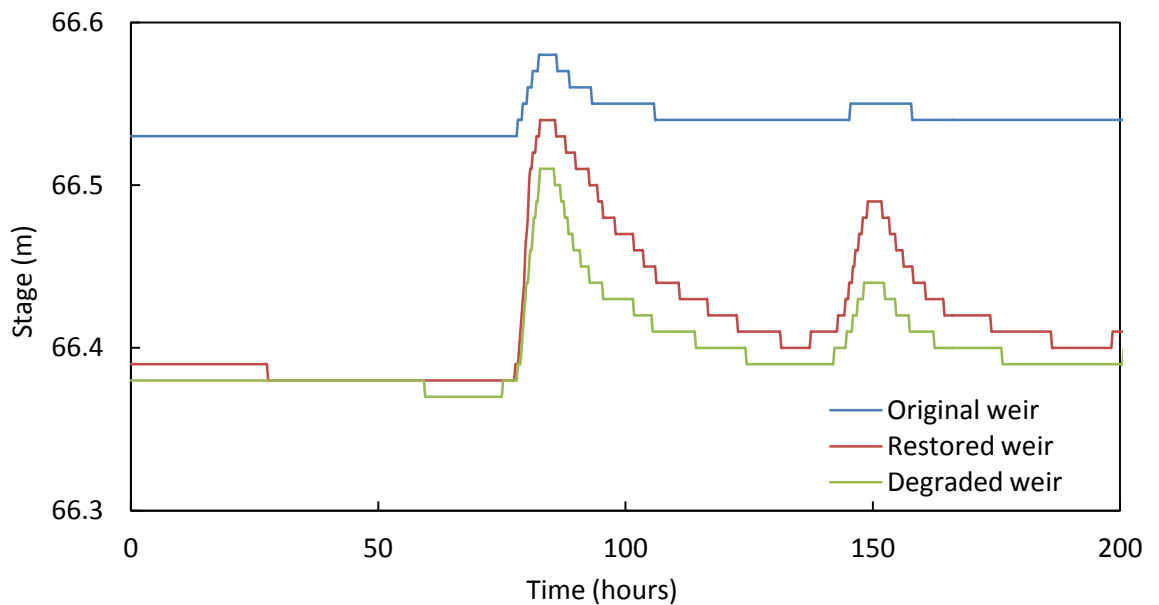


Figure 7.16 Water elevation behind weir (XS 4.04) for three simulations with profiles for original, restored and degraded weirs. The restored and degraded weirs result in 4% and 8% (respectively) decrease in the flow area, when compared to the original weir

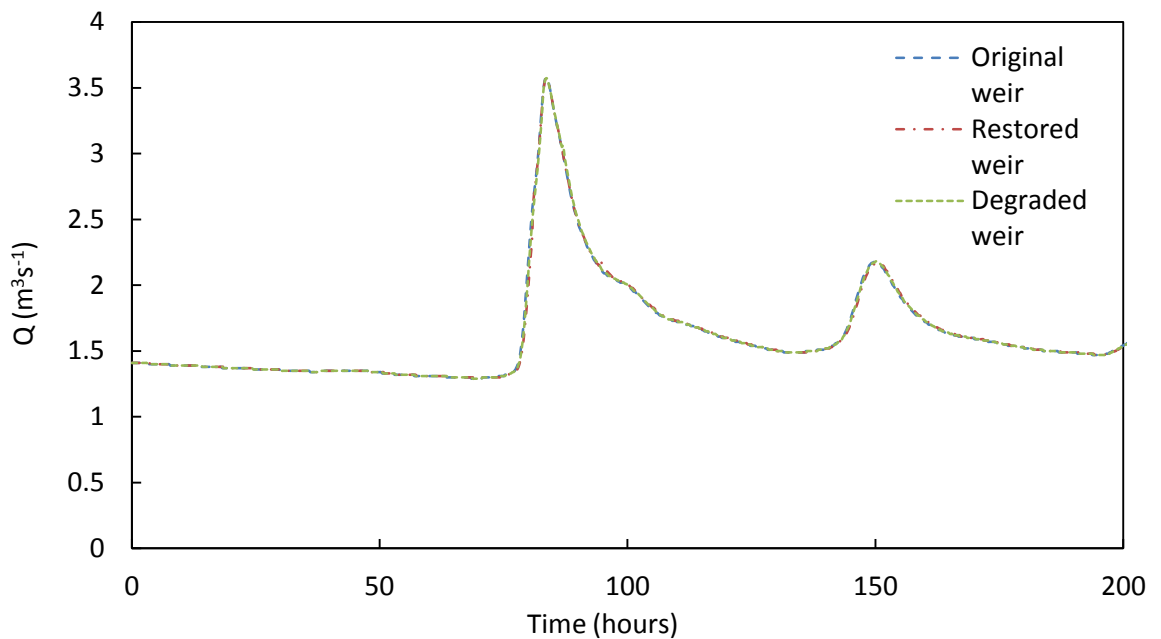


Figure 7.17 Flow behind weir (XS 4.04) for three simulations with profiles for original, restored and degraded weirs

Downstream of the weir, there appeared to be no impact on water stage or discharge (Figure 7.18). While there was no impact on overall discharge upstream of the weir, a difference in stage for the three weir profiles was predicted and this impact diminished with distance from the weir (upstream). Two metres upstream of the weir, the impact on stage was predicted to be the same as just behind the weir and this effect remains the same for approximately 100m upstream of the weir (Figure 7.19). By 200m upstream, the impact begins to lessen, with the profiles for the degraded and the restored weirs producing almost identical stage hydrographs, and at the highest flow, the stage for all three weir profiles is roughly the same, at around 66.67m. While there is much variability, over time, in the stage hydrographs predicted for the restored and degraded weir profiles, the original weir profile produces a more stable stage hydrograph. This impact is reduced with distance from the weir and by 200m upstream, the stage hydrograph for the original weir profile becomes more flashy and mirrors the shape of the restored and degraded hydrographs, most likely due to the buffering effect of the weir on stage diminishing with distance from the weir. It is expected that the restored and degraded weir profiles create more flashy stage hydrographs due to the area available for flow passage below the top of the weir. The original weir profile has the smallest area of degradation through which the flow can pass, meaning that the flow is obstructed, water level is higher and as the width of the cross section increases, small changes in flow volume have little effect on stage. As illustrated in Figure 7.19,

this effect lasts for around 200m upstream, which is concurrent with observations made by the Competence group that the pool upstream of the weir in which water is 'still' (and in which they are able to boat), stretches around 150-200m. One kilometre upstream of the weir, all of the impacts associated with different profiles have been lost.

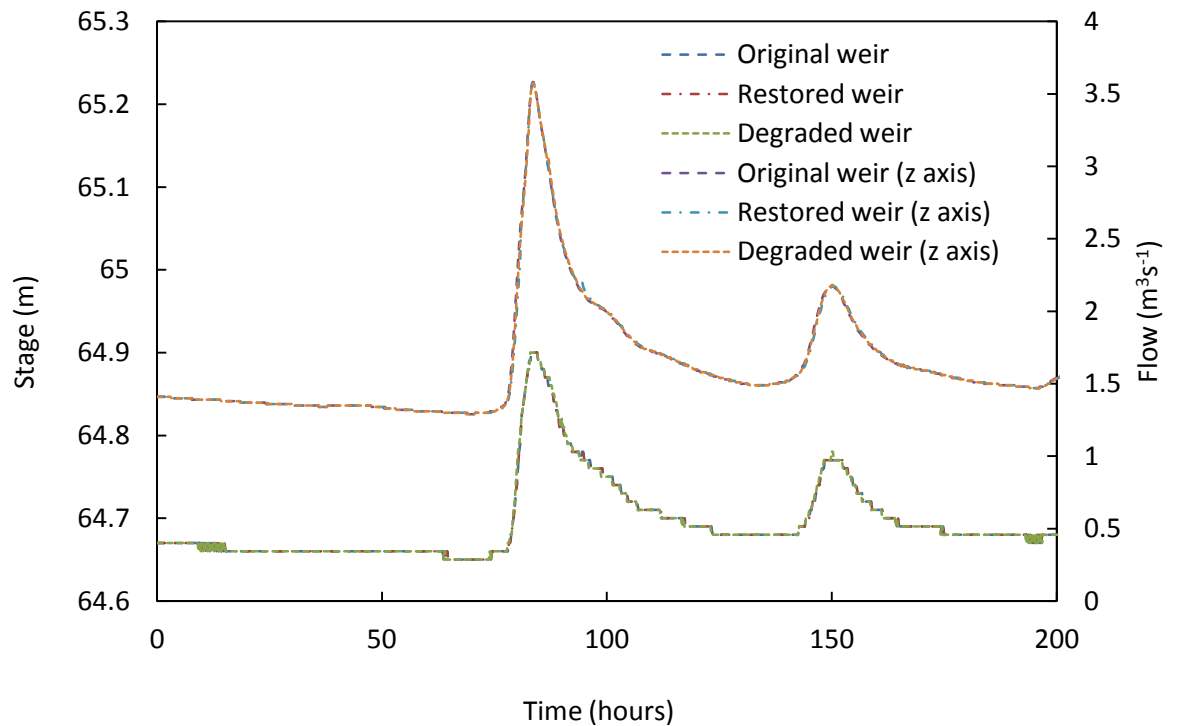


Figure 7.18 Flow and stage downstream of weir (XS 4.03) for three simulations with profiles for original, restored and degraded weirs. Weir profile had no impact on stage or flow rate downstream of the weir

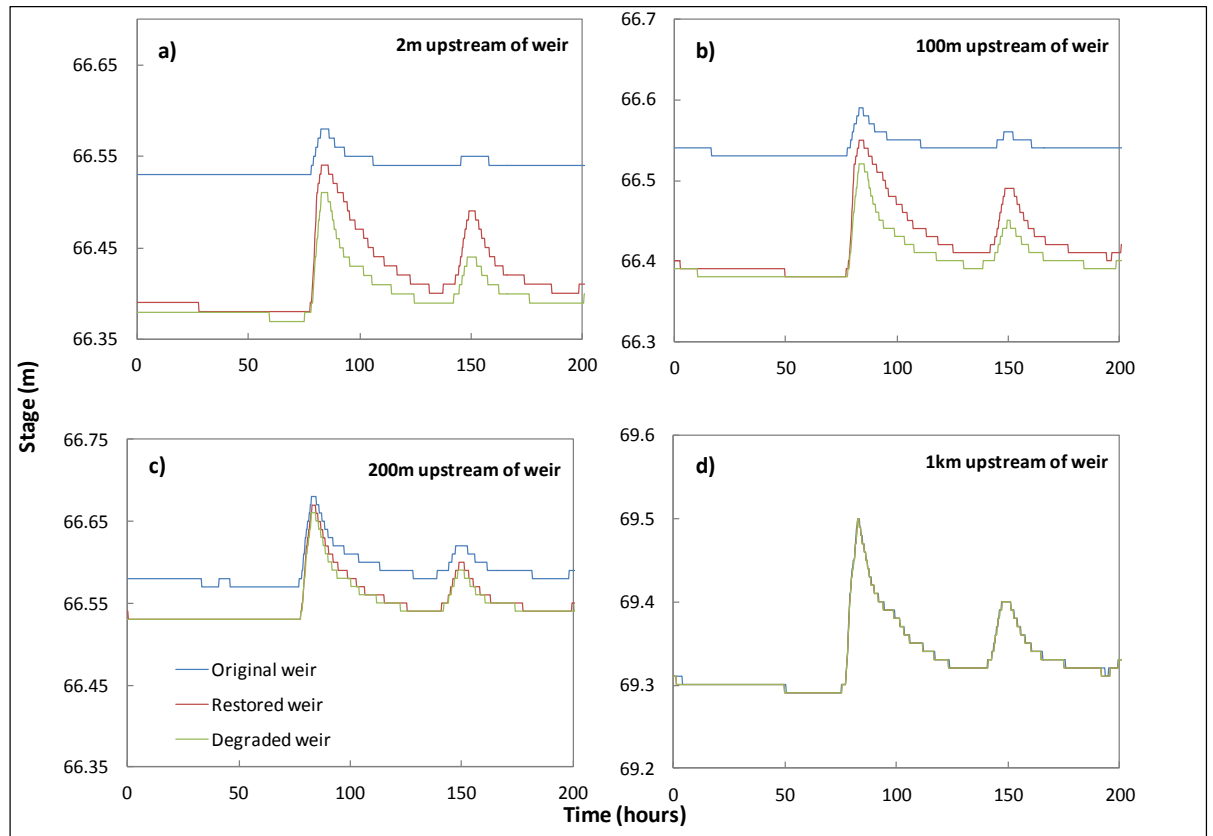


Figure 7.19 Changes in stage with increasing distance from the weir (upstream) in response to the original, restored and degraded weir profiles

The impacts of the different weir profiles described above refer to a situation where the weir profile has changed, but there has been no alteration to the sediment profile. In reality, it is likely that the form of the cross section would change in response to a change in weir profile and the change in sediment distribution or cross section would then impact upon stage. To test this, the model was run with the sediment transport component enabled (see description in Section 7.2.1.4 and detailed results in Section 7.3.2) and the cross sections that were produced after one year with the restored weir profile were entered into the model that was set up to simulate the change in water level (still with the restored weir profile). Although the new weir profiles caused some changes to the cross sections as a result of sediment transport (see Section 7.3.2), there was minimal impact on water stage as a result of the new cross sections. Figure 7.20 shows that the effect (on stage) of changing the weir shape is far greater than the new cross sections that are formed as a result of sediment transport following a change in weir shape. In other words, the sediment transport under new weir profiles does not impact the cross sections enough to significantly change the stage hydrograph (according to model predictions). It is likely that this is due to the width of the cross section and the minor impact that a change in sediment depth would have when distributed over this width. In addition to this, the gaps in the weir already

exist, the new profiles simply increase the size of them. It is expected that if a new gap or a new weir was created, this would have a much more significant impact on the rate of flow behind the weir and therefore the ability of the flow to transport (or deposit sediment) at this point.

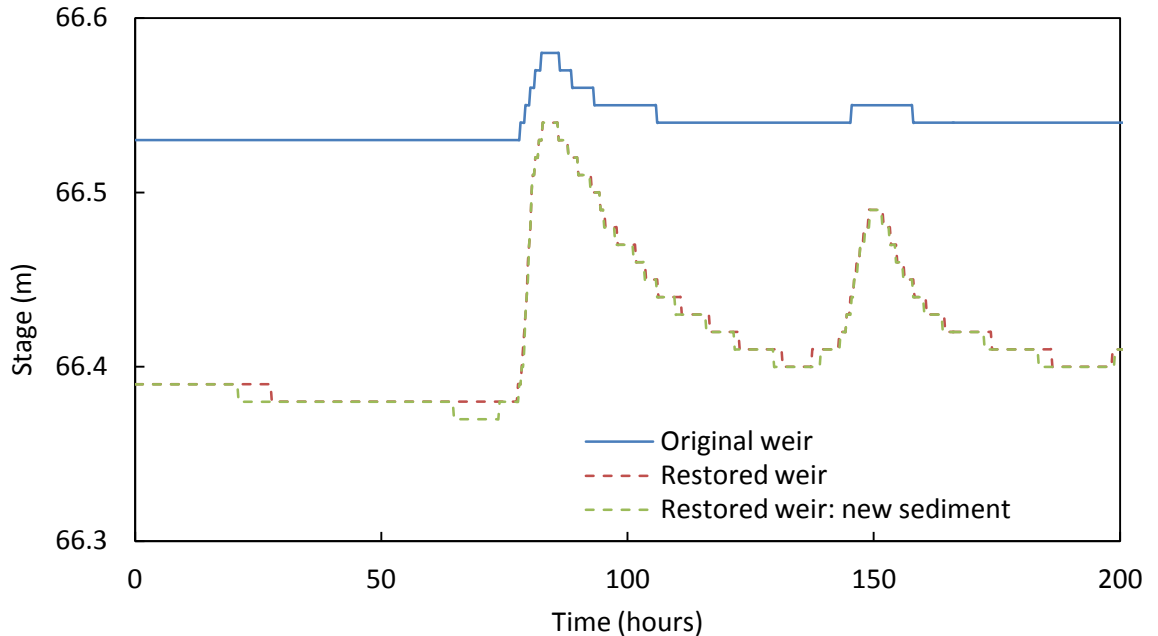


Figure 7.20 Water elevation behind weir (XS 4.04) for three simulations with profiles for original, restored and degraded weirs, with cross section profiles updated after running model with the sediment transport component

7.3.2 Sediment accumulation and deposition

The impact of changing the weir profile on sediment accumulation in the pool behind the weir was assessed using the sediment transport component of HEC-RAS. The model was set up as described in Section 7.2.1.4 and run with each of the three weir profiles (Figure 7.15) in turn. Any changes to sediment cross section profile behind the weir were recorded. There were small changes in bed elevation for the cross sections upstream of the weir (Figures 7.21 and 7.22) after one year of simulation. However, this change is small (generally less than 10cm) and is relatively consistent for all of the weir profiles, suggesting the main change in bed elevation is a result of the natural sediment movement that would occur in any channel, rather than the new weir profiles causing effects such as a build-up of sediment behind them, or an increase in erosion rates. Downstream of the weir (Figure 7.23), the model suggests that there would be a significant increase in bed elevation (i.e. deposition) and that this would be very slightly more prominent with the degraded weir. However, the distinction between the weir profiles is again minor in comparison to the general change from one year to the next. What the results do suggest is that

any form of barrier at this point on the river may cause accumulation of sediment just downstream, perhaps due to the concentration of flow into one or two areas over the weir (although there is no evidence in the results to suggest that certain parts of the cross section experience lower levels of accumulation where flow is concentrated). With distance downstream from the weir, the overall rate of accumulation reduces (Figure 7.24), which is supportive of the competence group observation that the area around the bar is stable due to the dense vegetation on the bar and some 'mossy rocks' on the bed, and there is no distinction between weir profiles at this point. Although the changes in cross sections discussed are small, Figure 7.25 shows that the changes in mean elevation of cross sections is most pronounced around the area of the weir, supporting the observation that a barrier in some form has an impact on sediment transport rates, but that subtle changes to the shape of that barrier are negligible.

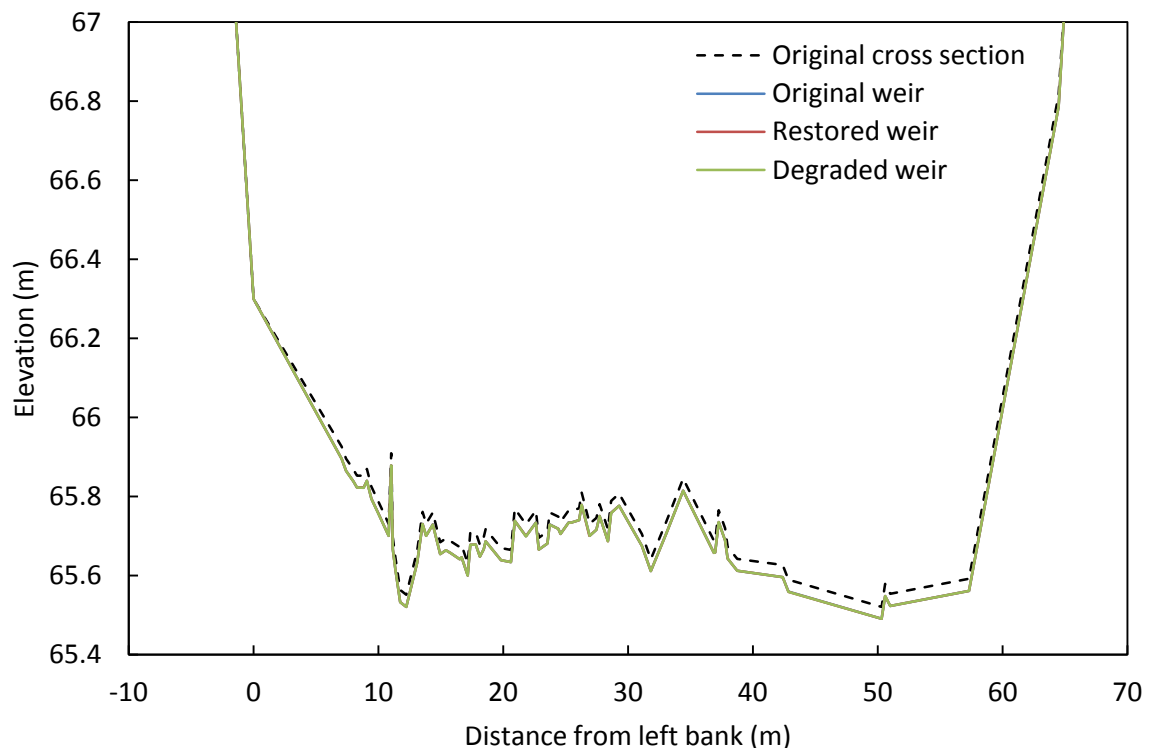


Figure 7.21 Cross section 4.09: change in shape in response to changing weir profile. Based on sediment transport modelling over one year, starting with the original cross section profile measured in the field

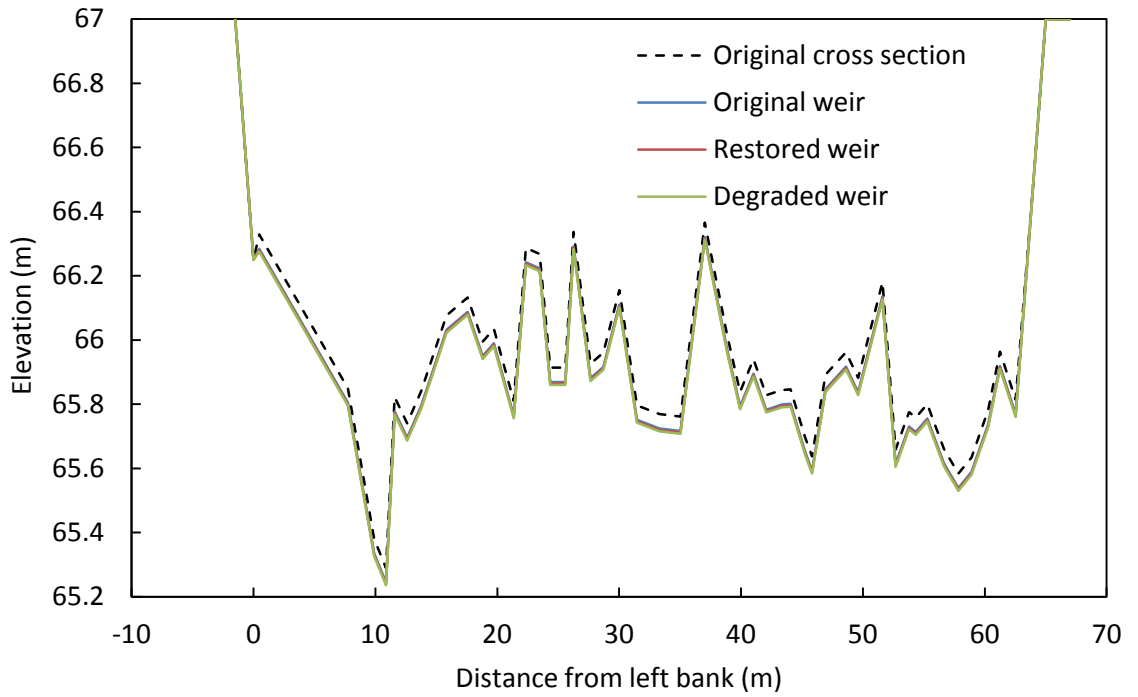


Figure 7.22 Cross section 4.05: change in shape in response to changing weir profile. Based on sediment transport modelling over one year, starting with the original cross section profile measured in the field

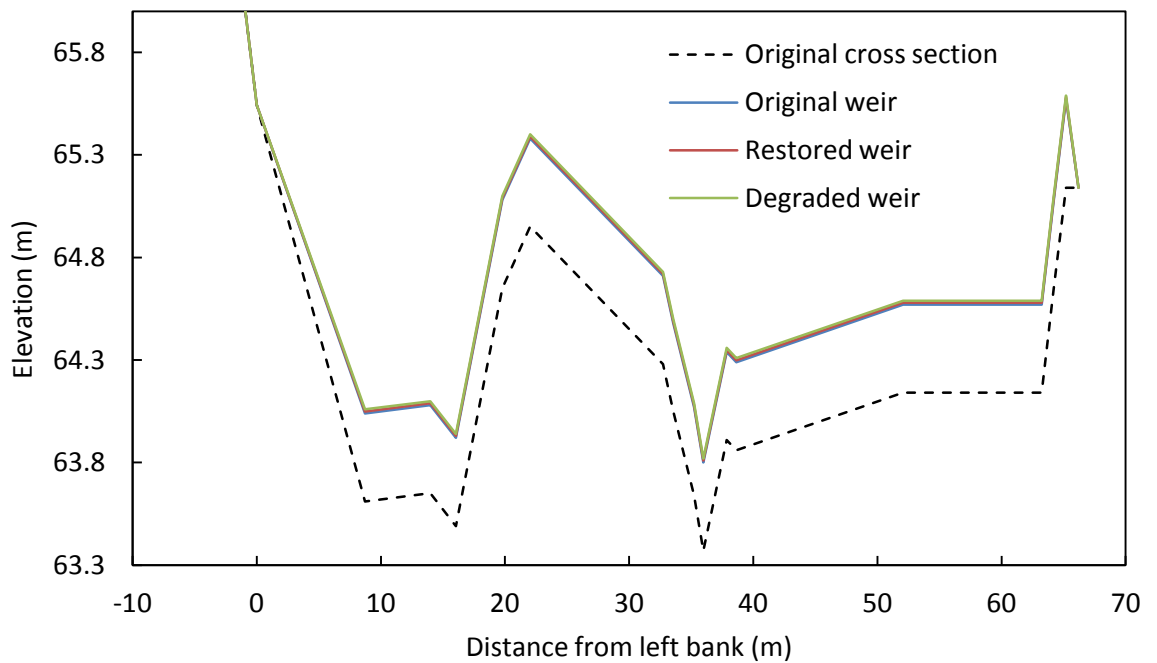


Figure 7.23 Cross section 4.03: change in shape in response to changing weir profile. Based on sediment transport modelling over one year, starting with the original cross section profile measured in the field

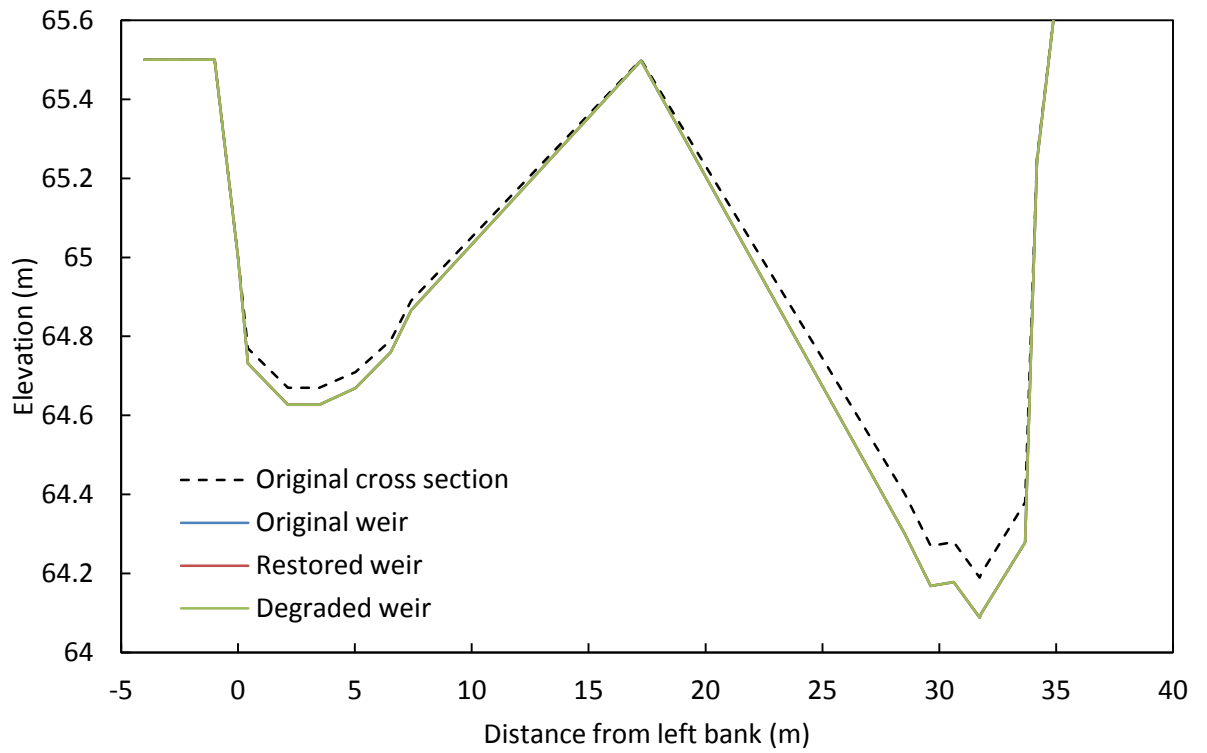


Figure 7.24 Cross section 4.0031: change in shape in response to changing weir profile. Based on sediment transport modelling over one year, starting with the original cross section profile measured in the field

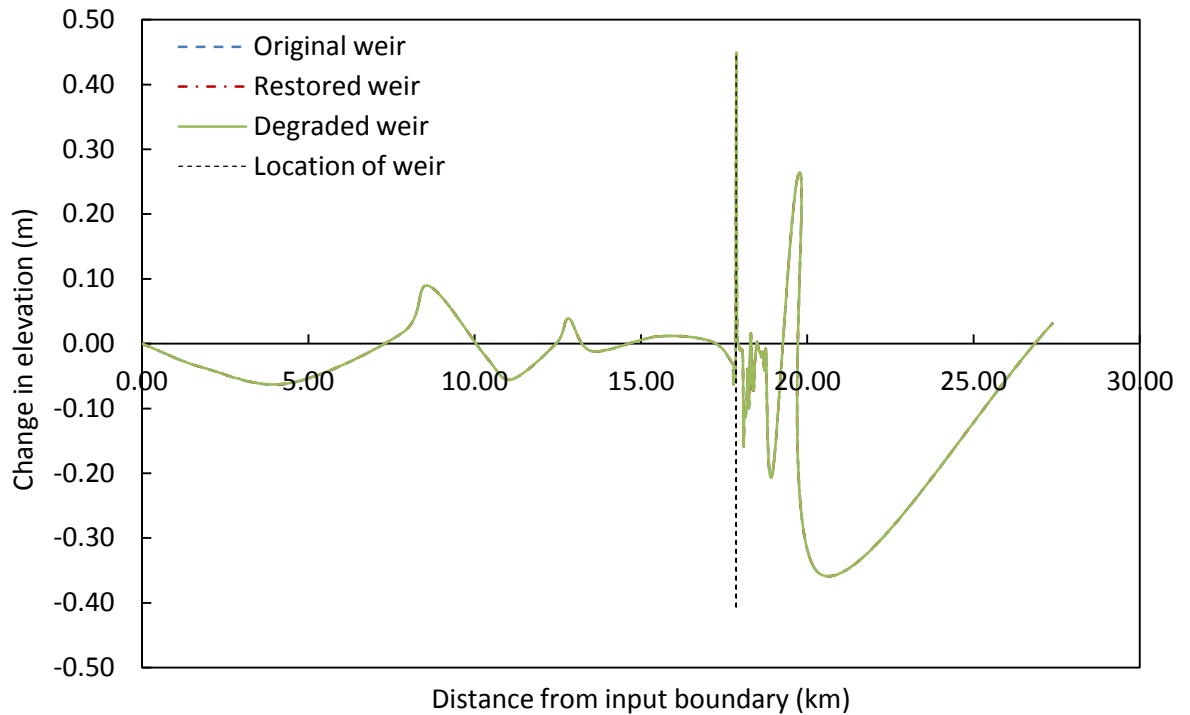


Figure 7.25 Change in mean channel elevation for each cross section after a year with various weir profiles in place (weir is 17.86km from input boundary). Most prominent channel elevation changes occur close to the site of the weir but actual weir profile has limited impact on nature or magnitude of change

7.3.3 Vegetation removal

Because vegetation is represented as a roughness coefficient (which determines within the model how much friction is caused by different types of channel boundary), the impact of removing vegetation from the central bar could be assessed by varying the roughness coefficient of that bar within the model. At present, the bar is largely overgrown and is dominated by trees and heavy undergrowth which extends to the bar/water boundary. According to the Manning's n classifications consulted earlier in the study for model setup and calibration (e.g. Chow, 1959), the current state of the bar would be considered to have a value of 0.1. A number of scenarios were represented using Manning's n values selected from the USGS, HEC-RAS (US Army Corps of Engineers, 2010a) and Chow (1959) classifications (Table 7.11).

Scenario	Manning's <i>n</i>	Description in HEC-RAS user manual (originally from Chow, 1959)
Original <i>n</i> value assigned in calibration process	0.025	
Current state of dense vegetation on bar	0.1	Heavy stands of timber, few down trees, little undergrowth, flow below branches <i>n</i> =0.1. (HEC-RAS classification code: 2.D.iii).
Vegetation cleared from bar	0.03	Short grass 0.025, 0.030, 0.035. (HEC-RAS classification code: 2.a.i).
Bar allowed to re-vegetate for a number of weeks (or bar cleared of vegetation but with large trees remaining in the centre)	0.035	High grass 0.030, 0.035, 0.050. (HEC-RAS classification code: 2.a.ii).
Bar allowed to re-vegetate for 6-12 months (depending on season)	0.05	Scattered brush, heavy weed 0.035, 0.050, 0.070. (HEC-RAS classification code: 2.c.i).

Table 7.11 Manning's *n* values used in assessment of impacts of bar vegetation removal. Descriptions are sourced from the HEC-RAS User Manual (US Army Corps of Engineers, 2010a)

Total discharge at the maximum water surface elevation, the maximum water surface elevation, and channel velocity at the maximum water surface elevation were chosen as important flow characteristics for comparison. The value of each of these characteristics for each of the different vegetation scenarios was compared, and this was repeated for a number of cross sections, from some just upstream of the bar (XS 4.03, 4.01, 4.0040: see Figure 7.3 for all cross section locations), at the head of the bar (XS 4.0035, 4.0030), every 10m along the length of the bar, and at downstream cross sections (XS 4, 3, 2, 1). The results for each scenario are represented as percentage difference of the result given for the Manning's *n* of 0.1 (i.e. the current vegetation scenario), for the total discharge and velocity analyses. The stage analysis is represented by change in water surface elevation, in metres, because the variability of the overall cross section height would produce a very small percentage difference between stages in response to roughness changes.

There was no change to the total discharge at the cross sections upstream of the bar or along the length of the bar, but there was an increase in total predicted discharge for the cross sections downstream (Figure 7.26). The percentage difference between the results of different scenarios for cross sections 4, 3 and 1 are small, ranging between 1 and 3 per cent. However, at cross section 2, the predicted total discharge for the 'cleared vegetation' scenario and the current vegetation scenario is -7.6%. Greater resistance around the bar will cause water to move more

slowly through the bar reach. This will mean that the peak flow downstream is likely to be lower and last longer than if the water moved through the bar reach quickly.

The main impacts on maximum water elevation occurred locally to the area in which the roughness values were changed (Figure 7.27). There was an overall increase in maximum water surface elevation as the roughness values increased, with the difference in elevation between $n=0.03$ and $n=0.1$ ranging from 0.23m to 1.27m, depending upon cross section shape and width. The impact on water surface elevation propagated downstream by 1.8km to cross section 4, but changes to water surface elevation further downstream than this did not exceed 0.01m. Upstream of the bar, water surface elevation increased as roughness increased, with a maximum difference in elevation of 0.27m. These observations suggest that dense vegetation around the bar causes flood peaks in that area to be significantly higher than experienced when the vegetation is cleared. The dense vegetation will increase flood peaks both by slowing down the rate of flow and causing water to be held back in that location, but also by reducing channel capacity.

Velocity predictions at the maximum water surface elevation showed the most variation between cross sections and also had a much greater percentage difference between the fully vegetated and cleared vegetation scenarios than was seen for total discharge (Figure 7.28). Again, the impacts were most pronounced where the changes were made (i.e. in the cross sections along the bar). The greatest increase in velocity occurred at the cross section at the head of the bar, the most upstream section where the roughness value was changed. Increases in velocity concurrent with decreases in roughness were also predicted for the cross sections upstream of the bar, to a lesser degree, while downstream of the bar changes in velocity were negligible. As discussed for water surface elevation, a decrease in friction will decrease drag and increase velocity locally, allowing flow to pass through a section more quickly. If the flow around the bar is able to move through more quickly, then the flow just upstream will not be 'backed up', thus allowing an increase in velocity at cross sections 4.03, 4.01 and 4.0400 also.

Notably, the shape of the weir had no impact at all on the results. The total discharge, maximum water surface elevation and velocity values for each scenario at each cross section, were identical for each weir profile. This supports the findings in Section 7.3.1, which suggest there is no change to the stage or flow hydrograph downstream of the weir, regardless of the profile.

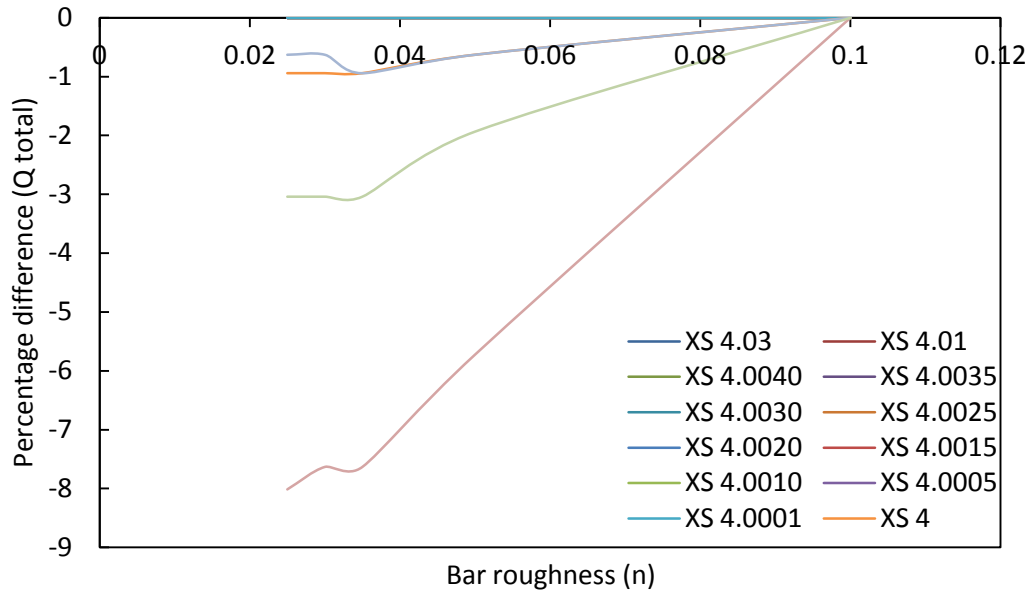


Figure 7.26 Percentage difference between total discharge results at various cross sections, based on original bar roughness of 0.1 and other roughness coefficients designed to represent varying degrees of vegetation growth (difference in discharge is calculated at maximum water surface elevation for that simulation) Cross section locations are illustrated in figure 7.3

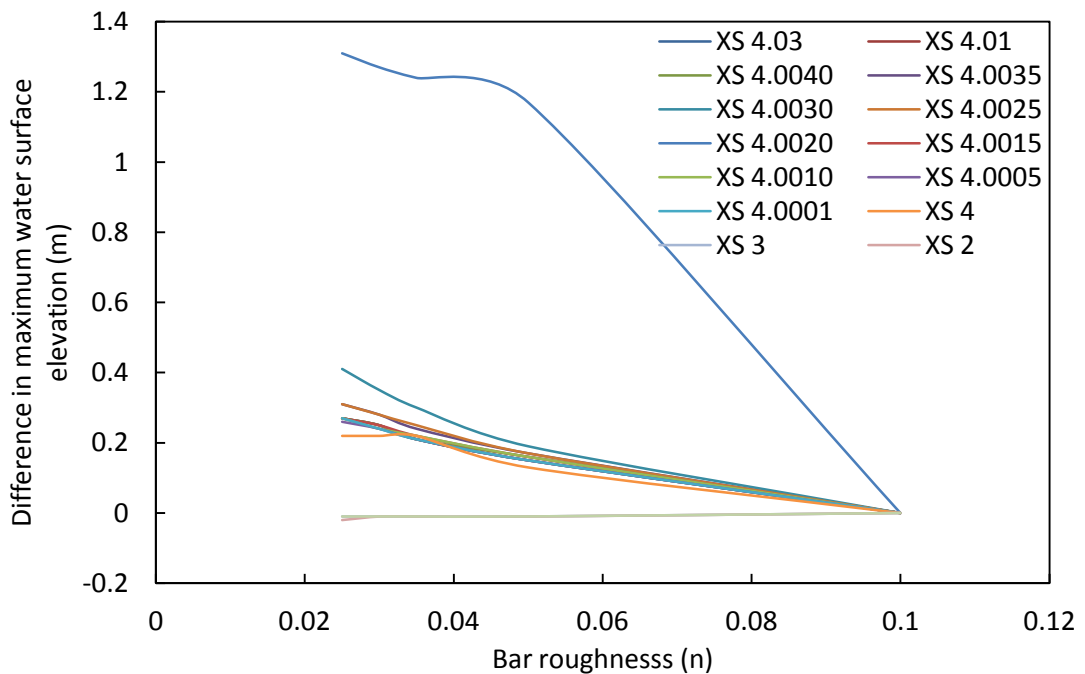


Figure 7.27 Percentage difference between maximum water surface elevation results, based on bar roughness of 0.1 and other roughness coefficients designed to represent varying degrees of vegetation growth . Cross section locations are illustrated in figure 7.3

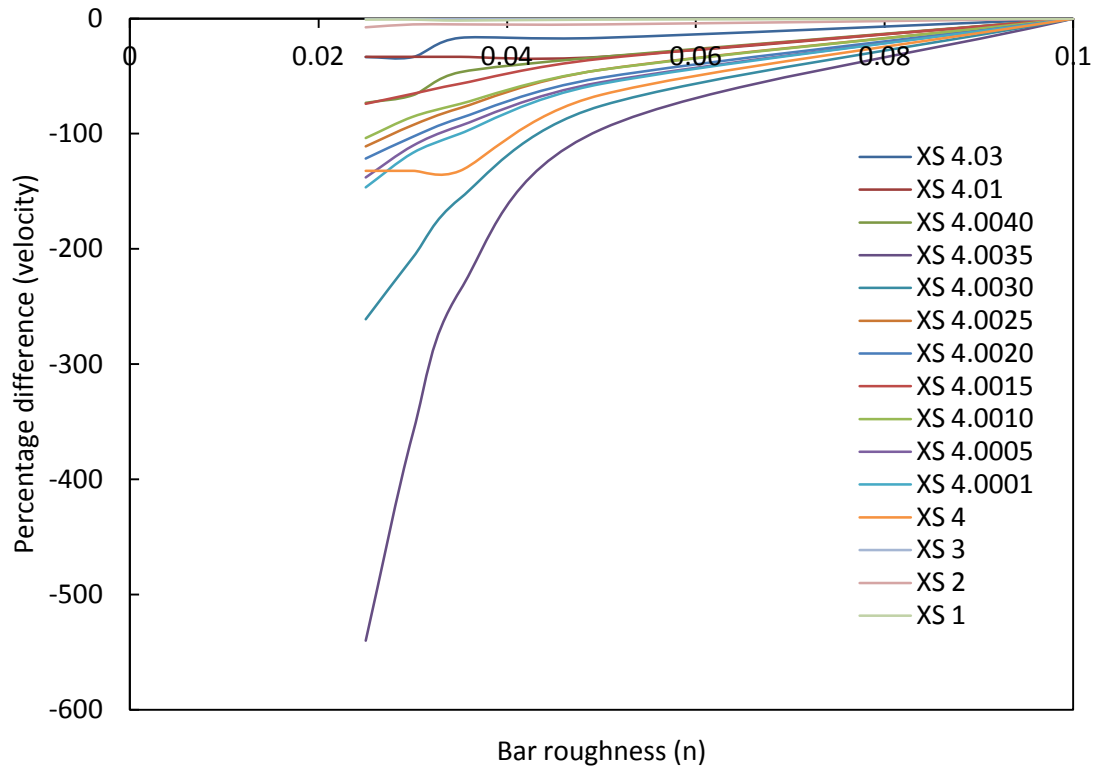


Figure 7.28 Percentage difference between channel velocity results, based on bar roughness of 0.1 and other roughness coefficients designed to represent varying degrees of vegetation growth (difference in discharge is calculated at maximum water surface elevation for that simulation). Cross section locations are illustrated in figure 7.3

7.4 Conclusions and use of results

This chapter has outlined the approach to hydraulic modelling specific to this study. It began with an explanation of model choice (HEC-RAS), based around the need for a model which was computationally efficient and accessible. HEC-RAS was chosen for these reasons and also because it is a standard industry tool, particularly important for communicating results with Competence group members and providing consistency between tools used by the Environment Agency (about whom the Competence group have many questions) and the work carried out for this project. The input data for the model consist of 15 minute flow data derived from gauged stage recorders and topographical data which were collected using a combination of techniques including a dGPS, EDM and TLS. Roughness coefficients were assigned to each cross section using a standard photographic comparison method (Chow, 1959) and were calibrated to the model in the

parameterisation process, in which the best achievable fit was found between the observed and predicted data. The benchmarking process showed that the model is spatially and temporally discretisation independent and the evaluation process showed that the model works reasonably well in predicting flow hydrographs to which it has not been calibrated. Therefore, the model was considered suitable for application to the questions developed with the Competence group (although it was not intended to independently produce definitive results for the group's cause).

The main questions of the Competence group were centred around issues of the impact that a new weir profile would have on the flow and sediment transport within the channel. These were tested by applying the model under a number of scenarios. First, it was shown that the hypothetical new weir profile, and hypothetically degraded weir profile have limited impact on overall flow rates upstream and downstream of the weir, but that the stage hydrograph upstream of the weir would be affected by each of the new weir profiles. This impact propagated upstream for a distance of approximately 200m. Incorporating a new set of cross sections based on sediment transport predictions suggested that the presence of a weir caused some overall degradation of sediment upstream of the weir and accumulation downstream, for a short distance, but that subtle changes in the shape of that weir had limited impact.

A more detailed investigation of the impacts of the weir profiles on sediment transport supported the observation that it is the presence of a barrier within the channel that has the greatest impact on sediment transport and deposition, but that there were some minor differences in transport/deposition rates between the weir profiles at the cross sections closest to the weir. The most pronounced impact on overall sediment accumulation rate occurred just downstream of the weir, at cross section 4.03.

Finally, the impact of vegetation removal from the bar was examined in terms of total discharge, flow velocity and water surface elevation. The model predicted that small changes to total discharge occurred downstream of the area in which the roughness value changed, but that changes to velocity and water surface elevation were more localised.

These results will be presented to the Competence group in Chapter Eight, which will discuss the approach to results sharing, demonstration of the model to the Competence group, the response of the group to the results and how their responses were incorporated into the modelling process.

Chapter Eight

Case study findings, integration of knowledge and final model outputs

8.1 Linking scientific models with experiential knowledge

Chapter Seven presented the preliminary model results, designed to address the EWRG research objectives, which were discussed in Chapter Five. The modelling process was outlined, including data collection, model set-up, parameterisation, benchmarking and evaluation. The model was demonstrated to be able to predict the river's response to a number of management scenarios, based on conditions in which the original weir existed. The same scenarios were then applied to the system with hypothetically restored and degraded weirs. The impacts on water level in the upstream pool, sediment transport dynamics, and the implications of vegetation removal from the downstream mid-channel bar were assessed. It was found that the shape of the hypothetically restored weir would cause a drop in water level (by up to 0.15m for the test hydrograph), under the same flow conditions, when compared to the original weir, and that a degraded weir would result in the lowest water levels. This effect was predicted to propagate approximately 200m upstream of the weir. Sediment deposition upstream of the weir was predicted by the model to be minimal, one year after the weir is restored, although some deposition was predicted to occur immediately downstream of the restored weir. Changes in roughness in response to vegetation removal from the mid-channel bar were predicted to have localised impacts on velocity and water surface elevation, while limited changes to discharge occurred downstream of the bar area.

In this chapter, attention returns to the Competence group and their role in development of the preliminary model results. Although the Competence group were fully involved in the framing of the group's understanding of Ebchester weir and the River Derwent, as well as the design of the

EWRG objectives, their involvement in the actual data collection and modelling process was limited (due to the specialist skills necessary for data collection and model application, as well as the wish within the group to not be involved with the technical aspect of the process). It was agreed with the group that this was an appropriate approach and that further involvement should be based on review of the model outputs, and development of model applications, rather than the initial 'scientific' model development. In addition to this process being developed as a result of the wishes of the group, it is in accordance with the framework presented by Callon (1999), in which co-production of knowledge and high-level involvement do not necessarily require all participants to be heavily involved in all aspects of the research, but that different parties may still have specific roles, the emphasis being placed on how overall knowledge is created, shared and developed. In higher level participation processes, and in Mode 2 knowledge production in particular, Mirowski and Sent (2008, 667), highlight the importance of research which is now more responsive to external interests and concerns, is reflexive and which consists of heterogeneous knowledge sources. For this reason, the Competence group in this project were not simply asked to identify research objectives, and then presented with the results, but were given the opportunity to comment on preliminary model outputs and together, the Competence group were allowed to shape further development of the outputs, and therefore the knowledge and understanding of the impact of Ebchester weir, in its different states. One of the features which distinguishes Mode 2 knowledge production from Mode 1 (also applicable in other cases, for instance, Callon's co-production of knowledge from Public education or debate), is the use of novel approaches in quality control. In the present study, the discussion with the group which took place in Competence Group Meeting 4 (CG4, see Section 3.4.6) was intended to develop a novel form of quality control (that is, approval in terms of social and cultural criteria, as well as peer review (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001)), and to incorporate a range of understandings and experiences in reviewing the initial model outputs. This approach has been endorsed by a number of researchers in the field of river management, (e.g. Prell *et al.*, 2007; Henriksen *et al.*, 2009). Lane *et al.* (2011) discuss the importance of social robustness in environmental modelling and suggest that involvement of all parties in model development can lead to trust and acceptance by the group members, which in turn can serve as a form of model validation. One of the aims of the present study (further to a fully participatory process which was designed *by* and *for* the participants) was to achieve 'social validation' of the modelling process by discussing the model outputs for Ebchester weir, and developing the overall conclusions based on those discussions. According to Hessels and van Lente (2008), such a level of

involvement and deliberation can lead to knowledge production in which society speaks back to science (Nowotny *et al.*, 2001) and produces socially robust knowledge.

The benefits of a deliberative approach to model development, as outlined above, were part of the intended outcomes for this study. In the following sections of this chapter, the way in which this was pursued will be described. The chapter begins with an outline of how the preliminary results were shared with Competence group members and how the opportunity was developed to reflect upon the results, and offer feedback, opinions and suggestions for further development. The new questions which were raised will then be outlined, along with the approach taken to address them (which was agreed between the competence group members and myself based on time and skills available, and research priorities at that point). The revised model outputs will be presented and discussed within the physical context (i.e. developing an understanding of what the different scenarios might mean in terms of physical features such as flow and morphology). The chapter will conclude with a summary of the findings, group expectations and a note on accountability.

8.2 Sharing initial model outputs within the Ebchester Weir Research Group

8.2.1 Members of the Ebchester Weir Research group

The preliminary results (as presented in Chapter Seven) were processed for presentation to the EWRG. However, it should be noted at this point that during the period of initial model development, Durham County Council sourced funds and approved repair of the weir at Ebchester. This took place while the initial model set up (e.g. data collection, parameterisation, benchmarking and evaluation) was being conducted. To a number of the group members, the repair of the weir was the main and sole aim of the Ebchester Weir Restoration Project. As a result of this, and in combination with the length of time taken to collect field data and obtain communicable model results, a number of the group members became disinterested and decided that they no longer wished to participate. This is further discussed in Chapter Nine. For completion and to fulfil promises made at the outset of the process, the initial model results were collated and emailed to the group members who did not wish to participate for the full duration of the project, and they were invited to comment, should they wish. The information provided to these group members can be viewed in Appendix H. The discussion presented here is the one which was carried out with the group members who maintained an interest.

8.2.2 Presentation of information to the Ebchester Weir Research Group

In order to discuss the preliminary results with the EWRG, a PowerPoint presentation was created which detailed the process undertaken, from the time of the last meeting (CG3, field site visit), to the point of the meeting in which results were presented (CG4) (the full presentation can be seen in Appendix H). This included details of how field data were collected (and why), how they were prepared for use in the model, and a summary of the steps required in any modelling process. Figure 8.1 was designed to illustrate the types of data that were required for use in the model, and was accompanied by an explanation of how the data were used.

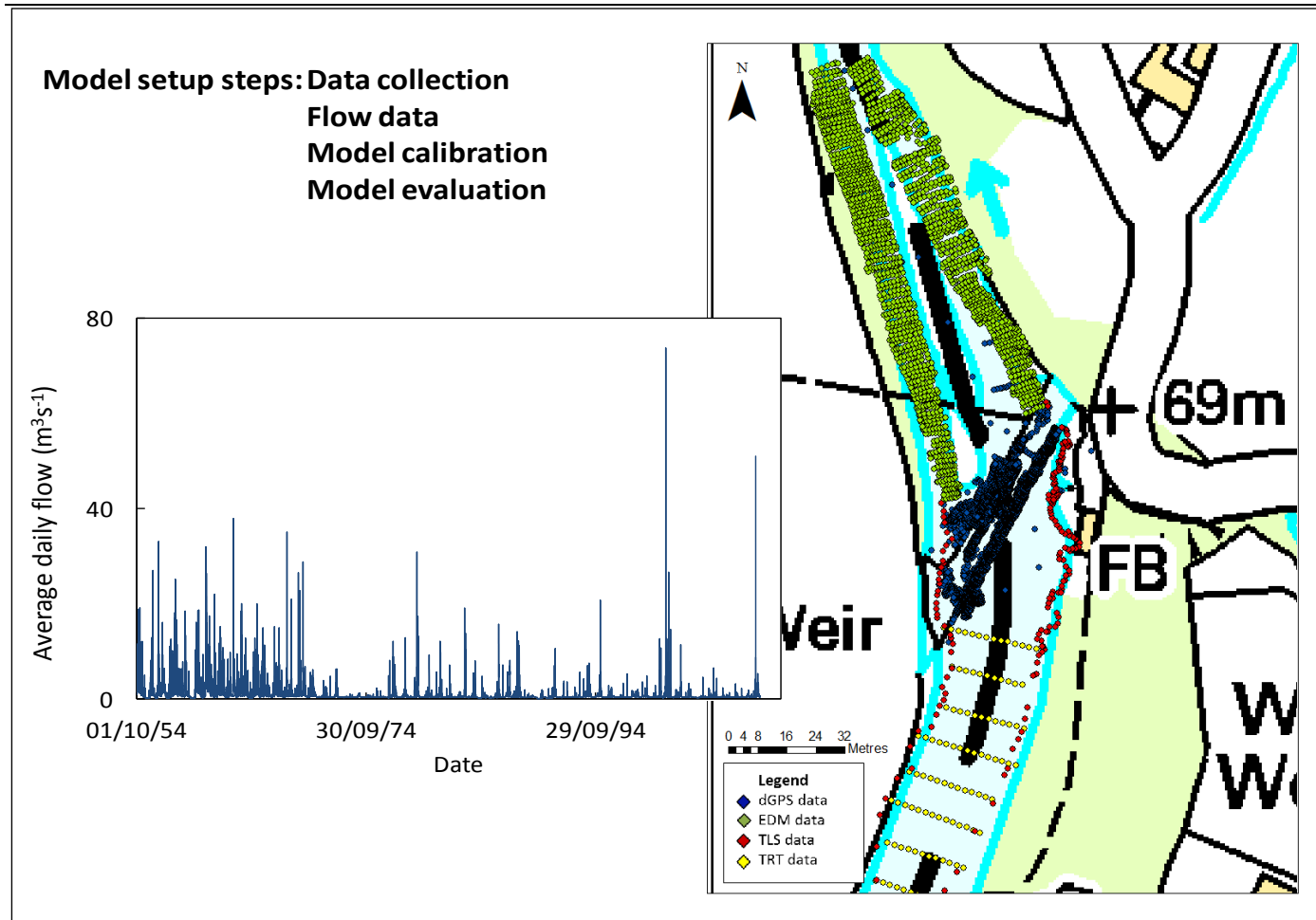


Figure 8.1 Slide used in CG4 to demonstrate long term flow data and DEM data required for use in HEC-RAS application to the EWRG questions. The slide was accompanied by a description of how the data were used in the model, how each type of data set was obtained and why a range of data collection methods was necessary.

Figure 8.2 was used to demonstrate to the group how gradual changes to the roughness parameters within a model help to 'tune' the model so that predictions are as accurate as possible. The concept of ' n ' (Manning's roughness coefficient) as a method of quantifying resistance to flow from boundaries, such as the bed, banks and vegetation (i.e. roughness) was explained for this part of the discussion and the 'traffic light' colour scheme used to show the outputs becoming progressively more accurate.

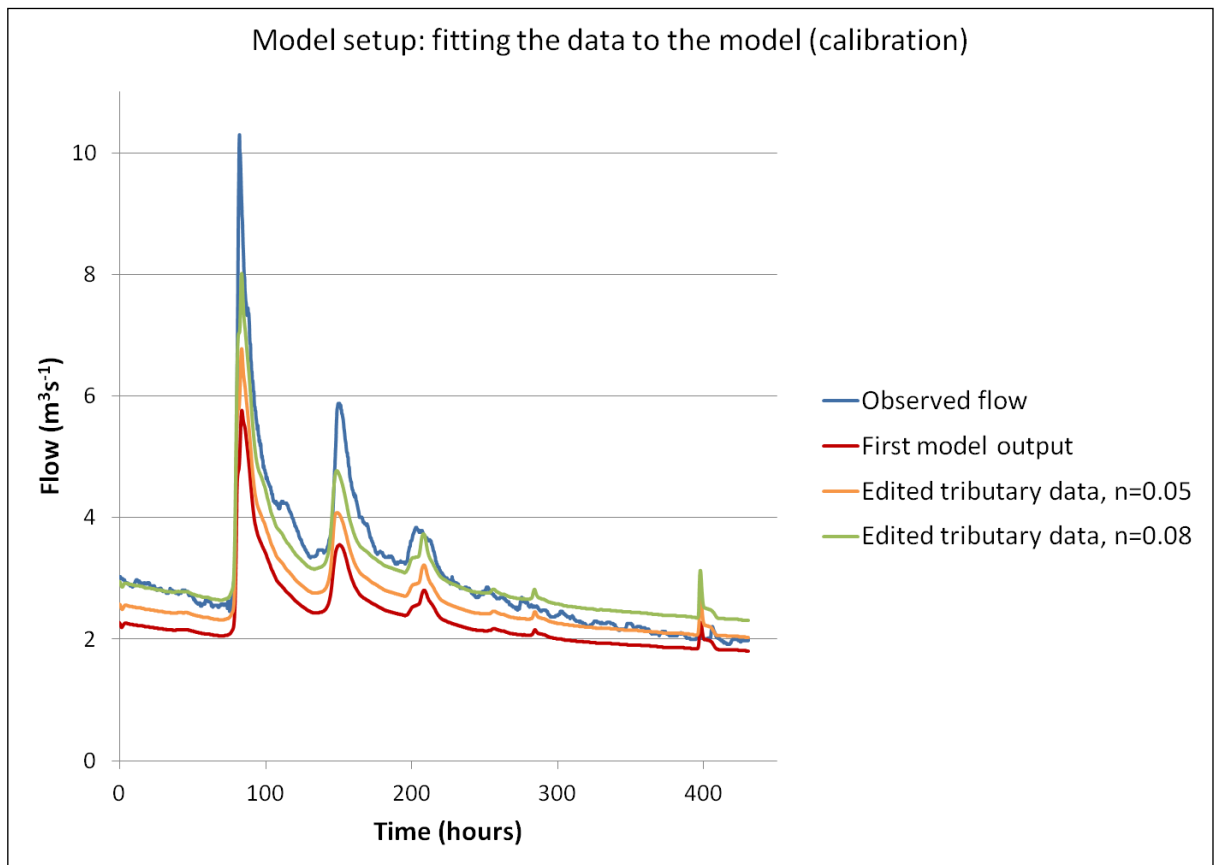


Figure 8.2 Slide used in CG4 to demonstrate the process of parameterisation and the range of model outputs for a number of different roughness (n) values

After outlining the process of parameterisation, the processes of benchmarking and evaluation (described as 'model assessment') were described (a summary of Section 7.2) and some validation statistics (including Nash-Sutcliffe scores, R^2 , and those presented in Table 7.10) were presented to the group to demonstrate the accuracy of model outputs. At this point, it was important to discuss with the group the issue of uncertainty, which is common to most modelling applications. It was imperative to the development of group trust and understanding to demonstrate that model outputs are not always fully accurate and that is something which must be acknowledged in river research. This was done by comparing the validation statistics (see Section 7.2.4), which

quantify the accuracy of predictions against observed data, for a number of different hydrographs. The group were able to see that although the validation statistics were not achieving the maximum score (e.g. Nash-Sutcliffe score of 0.89, which was presented to them as a strong score, but a perfect match is represented by a score of 1), that the model was able to reproduce most of the hydrograph reasonably accurately. This process also helped the group to identify that the model was least accurate for high flows and therefore consider that predictions (and associated conclusions) for these highest flows should be considered with more caution than predictions at lower flows.

After outlining the process of model set-up, the questions developed within the group at the end of CG3 (see Section 3.4.4) were reiterated and addressed in turn. The main finding for each question was summarised (Table 8.1), and illustrated graphically. Images such as the one in Figure 8.3 were used to demonstrate how the area of a cross section, water surface elevation, and velocity changed with distance downstream, and under varying conditions. The group were able to identify the position of the cross sections, based on their shapes, and some discussion was held over why velocity was so variable at different sites.

Findings for impact of different weir profiles on water level in upstream pool:	Findings for changes to sediment dynamics in response to a number of weir profiles:	Findings for vegetation removal from mid-channel bar:
Stage (water level) varies over time Original weir was most effective for water level behind weir <i>(question was raised over shape of new weir)</i> No impact on overall flow rate/volume No impact on flow OR stage downstream of weir	Used sediment component of HEC-RAS to quantify changes in sediment dynamics around the weir Some change both upstream and downstream of weir from the starting cross section No change to sediment as a result of changing weir profile	Changing channel roughness has little impact on overall flow volume, where there is change, it is to cross-sections downstream of the change in n . Change in maximum surface elevation of water varies between 0 and 0.5 m in response to roughness change. Changes are most pronounced locally to change in n . There is a varied response of velocity to change in channel n , most pronounced around area of n change.

Table 8.1 Summary of findings from initial model run, as presented to EWRG in CG4

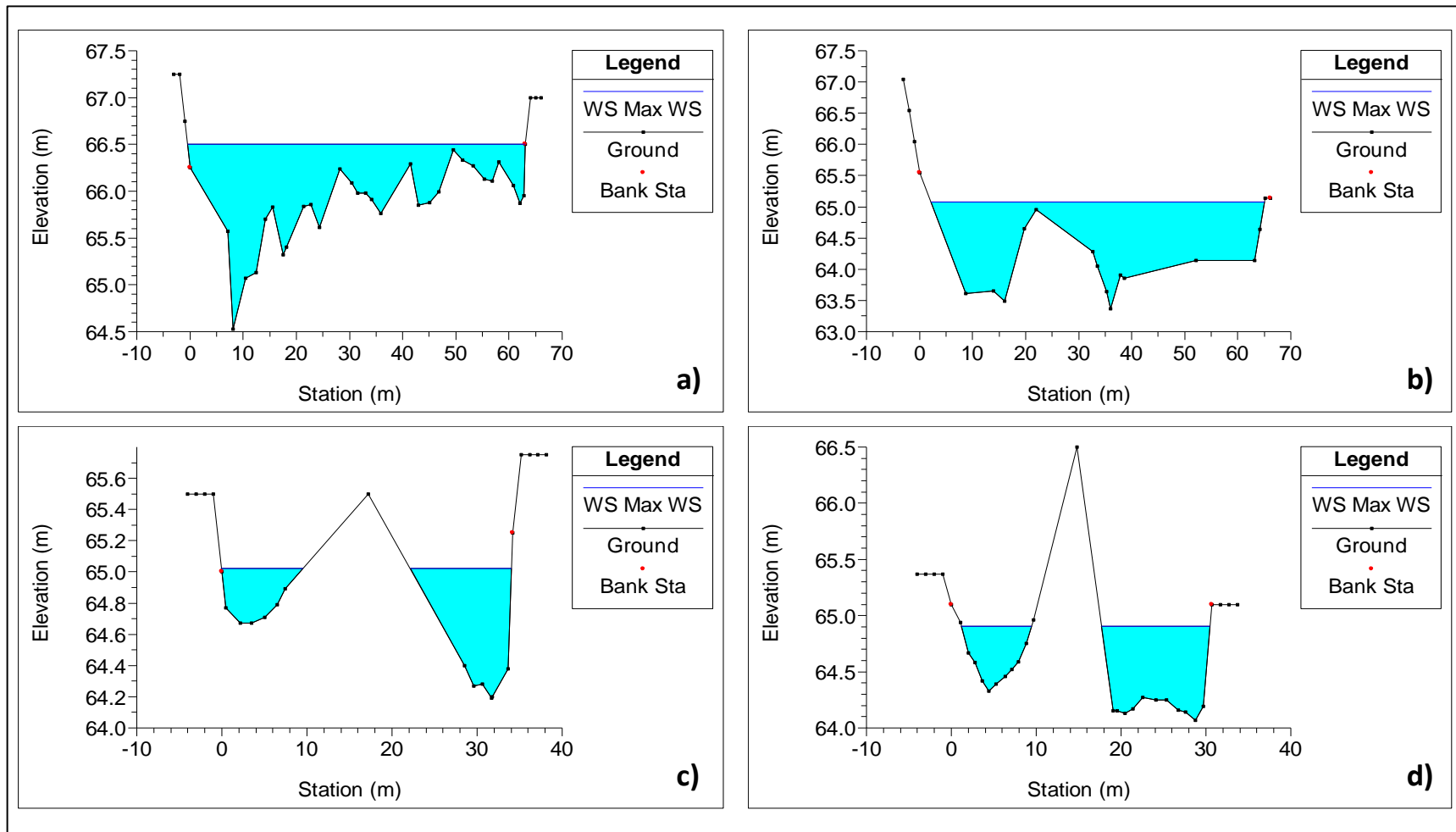


Figure 8.3 Cross section profiles used to illustrate the change in flow area and channel shape at a) 1m upstream of the weir; b) 1m downstream of weir; c) 30m downstream of weir and d) 50m downstream of weir

8.2.3 Model demonstration with Ebchester Weir Research Group

Following the summary of results, the HEC-RAS model itself was demonstrated to the group to allow them to view the different steps that would take place in a standard model run. Fields were shown for boundary data input (to demonstrate how the collected data were applied to the model), how to set the requirements for an individual model run, and the outputs that can be achieved (see Figures 8.4 to 8.6).

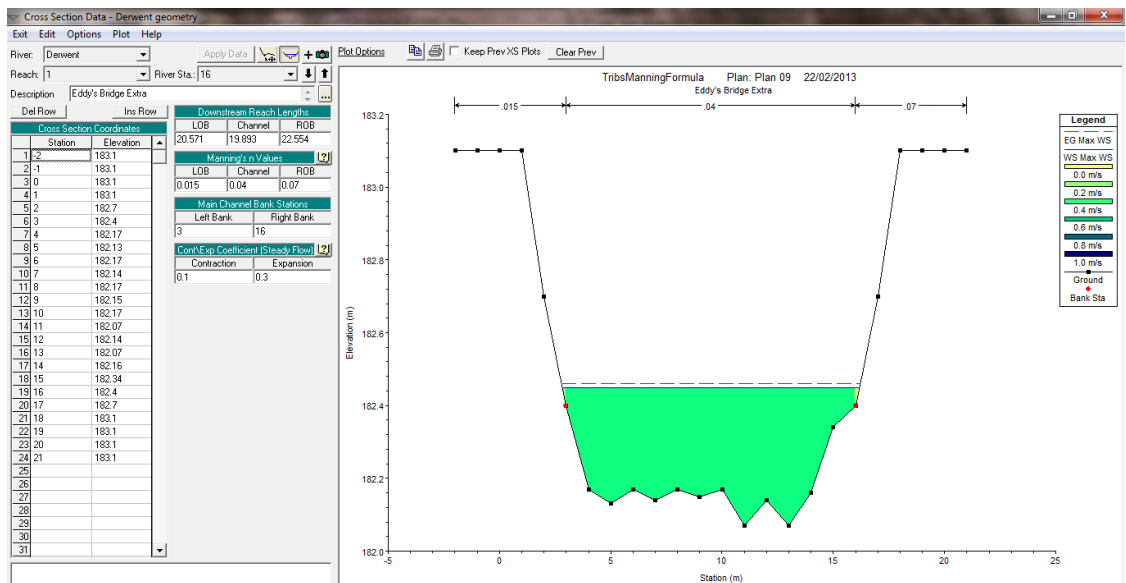


Figure 8.4 Example of application of geometry data (i.e. cross sections) for HEC-RAS application

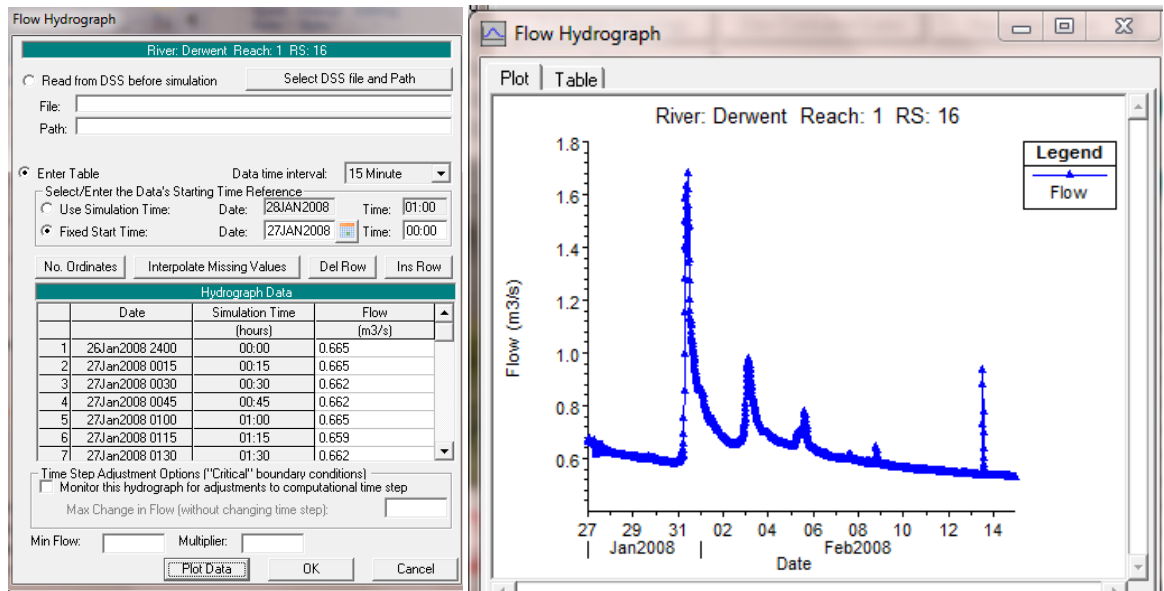


Figure 8.5 Application of hydrology data to HEC-RAS

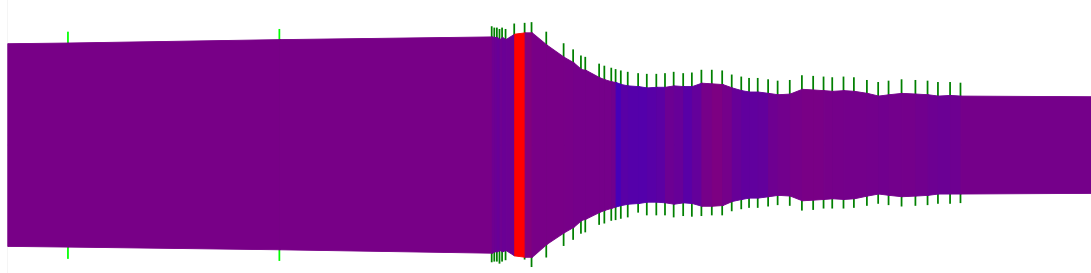


Figure 8.6 HEC-RAS illustration of change in bed elevation at various cross sections around Ebchester weir, one year after weir restoration (graded from red (lowest elevation change) to blue (highest elevation change))

The group were asked to comment on the model and the preliminary output (bearing in mind the model assumptions that had been discussed with the group). Discussions focused around what the model was able or unable to achieve, the issue of uncertainty and comparison of the model predictions with EWRG members' observations since the weir had been restored. The outcomes of these discussions are considered in the next section.

8.3 Ebchester Weir Research Group's reflections on the initial model results

8.3.1 Response to the model

Response to the model demonstration and preliminary results was one of enthusiasm and interest. The Competence group raised a number of points throughout the meeting, which were based around a number of viewpoints, including the danger of using derived data, with reference to the criteria used in the selection of a suitable hydrograph:

"cleaned-up data, always dangerous!" (M1 CG4)

The number of 'assumptions' used within the model caused some concern for the group members (such as rating equations used to calculate flow rate and the lack of model accountability for aspects such as run-off and degree of soil saturation during rainfall events). These assumptions, while standard practice for hydraulic modellers, clearly led to some surprise in the levels of uncertainty associated with modelling. This was a productive outcome as it helped the group to discuss, and to understand that model results should always be analysed with due consideration to the limitations of the model and of the input data used, and that individual output figures are not the single possible outcome, but the best possible prediction, based on information provided to the model. Further to this, the expected 10% level of error (US Army Corps of Engineers,

2010a), seemed to the group to be unacceptable, even though it is generally accepted within the modelling community, and the model is used as an industry standard tool to address Section 105 of the Water Resources Act (1991) (see Section 6.3.2). This served to highlight the different ways in which the same set of model results could be perceived by different people, based on individual experience. One group member summed up different perspectives of the approach:

“sometimes it’s not so much about making the model work, but knowing what’s going on [in the channel], that we’re not thinking about?” (M1 CG4)

It was observed by one of the group members that the river at Ebchester responded to rainfall events in different ways, depending upon extant catchment conditions (such as soil moisture content and amount of rainfall in the days before a specific event). This led to a discussion of the accuracy of model outcomes and the conclusion that while the model predicts flows reasonably well, there will always be external conditions which will affect the accuracy of predictions for each specific event. At this point, I discussed the role of hydrologic models, which when combined with hydraulic models, can offer a much more specific representation of an individual event, but it was noted by the group that the use of additional models would introduce further uncertainties to the predictions.

Discussion around the findings of the investigation into the impact of vegetation removal from the mid-channel bar helped to put the situation in context. The changes to water level, flow rate and velocity were subtle, and within the group it was decided that these changes would be insignificant when considered in the context of the rate of vegetation growth. It was noted that vegetation was cleared from the weir in preparation for its restoration, and also on the bar to remove some of the invasive species which populate that area, and that the vegetation was seen to re-grow within weeks:

“Having done all that, then to see what a dynamic thing that vegetation is....it’s like right across the top of the weir, when the water’s low in the summertime, it grows and you get all this stuff, and then in a flash it all gets swept away, and then it comes back again.” (M1 GG4)

As a result, it was decided that further investigation into such subtle impacts was futile and that that aspect of the investigation could be brought to a close with the conclusion that any amateur removal of vegetation would have minimal impact, would need constant and regular maintenance to sustain the small benefits, and may contravene WFD regulations concerning changes to flood risk and ecological status of the river.

The changes in bed sediment predicted by the model are small in comparison to the expectations that some members of the Competence group had, and this is a pleasing result for them which allays fears that some had about the impact on ecology in the river. The group questioned the effect that a high flow event would have on sediment, but the simulations that were run for sediment encompassed flow for an entire year (2008), which included the largest flood event in decades (1 in 56 years return period), and the one which many group members used as a frame of reference in discussions.

The Competence group concluded that, based on the preliminary results, the new weir profile appears to have limited impact on water level or sediment dynamics and that it is the presence of the weir that has the greatest impact, while subtle changes to its form have minimal impacts. However, the preliminary results raised questions over the impact that the small changes would have on area of flow in a cross section (for boating purposes), about the impact that a high flow event would have, and about the shape of the restored weir, as currently portrayed in the model. These issues are outlined in the following sections.

8.3.2 Development of the preliminary model

8.3.2.1 Shape of hypothetically restored weir

According to the preliminary model results for water level in the upstream pool, under different weir profile scenarios, the hypothetical shape of the restored weir, which was developed based on discussions held in CG1-CG3, causes the water surface elevation to be lower than the original weir profile does (see Figure 7.16). This was discussed in CG4 and it was found that this had not been the case, following the actual restoration of the weir. The water level is observed to have risen since weir restoration, on viewing the figures which show a lower water level for the restored weir, one group member comments:

“certainly this is not what happened....The observation doesn’t fit with that and indeed it’s the opposite so it needs to be thought through, it’s not what happens, so there’s some assumption somewhere or .. It went up about 25cm, it was a dry time [in terms of rainfall]” (M1 CG4)

The causes of this were discussed and the first point raised was that of rainfall at the time of observation of increased water levels. M1 notes that, for their own interest, they have collected some data regarding river depth and rainfall levels, since the weir restoration and this was used to show that the water near Ebchester weir appears to rise and fall rapidly in response to rainfall, while there has also been a gradual and maintained rise in water depth, since the weir was restored. These data were presented as a time series plot, as shown in Figure 8.7.

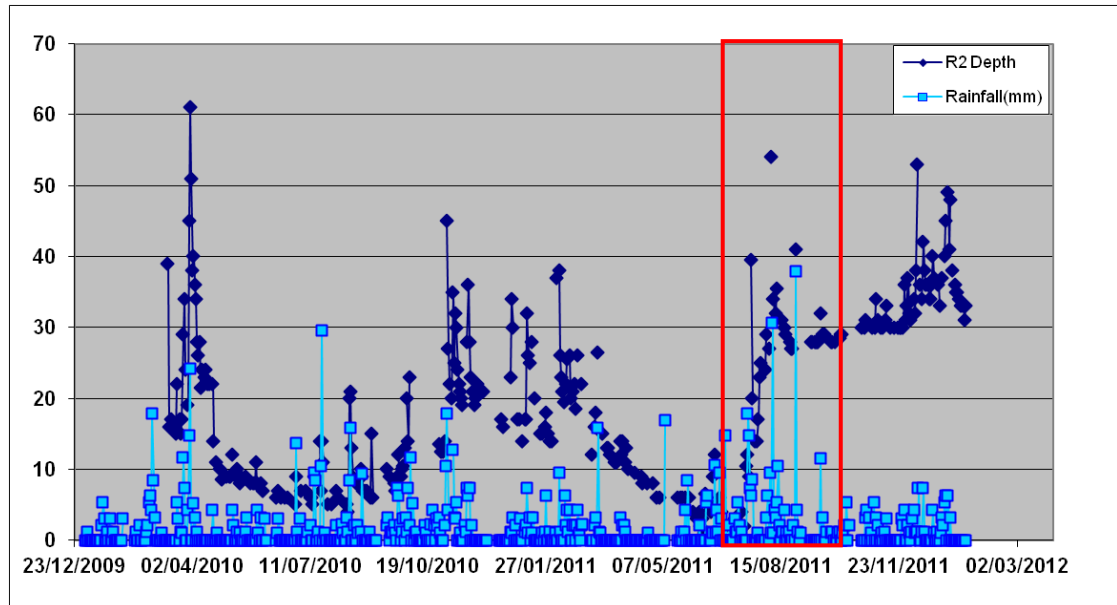


Figure 8.7 Rainfall and depth data for the River Derwent, collected by one of the group members for their own personal interest, and used to investigate possible causes of low estimation of water level from the HEC-RAS model. 'R2' refers to the location of depth measurement (cm). The time of the weir restoration, around 15 August 2011, has been highlighted for this thesis to demonstrate the rise in water level, even while rainfall is low. X-axis displays date and y-axis displays depth (cm) and rainfall (mm). Source: M1

Once the group had established that rainfall is unlikely to be the main cause of the rise in water level, the hypothetical shape of the restored weir within the model was discussed. It was agreed the new form of the weir was correct, but that dimensions may have been over-estimated. Photographic data were then offered by some of the group members, in order to re-assess the profile of the restored weir. Furthermore, one of the group members noted that although a low point in the right hand side of the weir (looking downstream) had been repaired, water still flowed over this point at a greater rate than over the rest of the width of the weir (excluding the fish pass at the opposite end). It was agreed that a new weir profile would be constructed and the model re-applied. Using the comments and photographs provided by the group, and some primary field measurements, the actual weir shape was created (see Figure 8.9) and the model re-run for water level and sediment dynamics investigations (details of these can be found in Section 7.3.1).

8.3.2.2 Impacts of a high flow event on the scenarios already investigated

The topic of water level in the upstream pool was of the greatest interest to the group and they wished to extend the understanding of the impacts of a new weir profile under high flow conditions, as well as 'normal flow'. To this end, it was agreed that the model simulations

performed to assess the impacts of a restored weir profile on water level (see Section 7.3.1) would be extended to accommodate a high flow event. One of the hydrographs used in the model evaluation process (and therefore with known validation statistics) was used for this purpose and the impacts of each weir profile (including the newly created restored weir) were assessed. This hydrograph had a peak flow in excess of the long term Q1 (i.e. the rate of flow exceeded for only 1% of the time), in the post-impoundment period, meaning that the test was applied to a hydrograph which contained the highest flow rate on record.

8.3.2.3 Usability of upstream pool with different weir profiles

In order to allow the results to be meaningful for those interested in boating, it was requested that the changes in water level be presented in a way which illustrated the change to *flow area* in the upstream pool. This was achieved by plotting the predicted water surface elevations against the original cross section profile, and annotating the illustration with the total area of flow, for two cross sections, one six metres upstream of the weir, and one 50m upstream of the weir (to include the main area of the pool used for boating and canoeing). This was repeated for each of the weir profiles for the original hydrograph simulations (i.e. those carried out in Section 7.3.1), and for the new high flow simulations.

The results of the new simulations for the developed modelling approach are presented and discussed in the next two sections.

8.3.3 Revised model outputs in response to review by Ebchester Weir Research Group

8.3.3.1 Re-design of the restored weir from local observations and photographs

The revised profile of the restored weir was developed to reduce the size of the gap at the point of the fish pass, and to allow a small amount of water to continue to flow over the weir on the right hand side (looking downstream), in response to photographs, observations and comments provided during CG 4 (Figure 8.8), the new weir profile was prepared and is illustrated in Figure 8.9. A fish pass was installed as part of the weir restoration, in accordance with government and WFD guidelines on works altering access of river reaches to fish. Much of the fish pass was built into the structure of the weir, but some of it protruded into what was previously the downstream river channel. The shape of the fish pass (see Figure 8.10) could not be accurately represented within HEC-RAS due to the number of steps that it produced within the channel over a small space (cross sections located too close together, i.e. less than one metre apart, can cause the model to become unstable). Therefore, analysis was conducted on geometry in which only the weir profile was altered and this will be the focus of this chapter. However, to gauge the degree of impact the

fish pass would have, the shape of the fish pass was incorporated into existing cross sections and the model run with this new geometry. The model outputs suggested that the shape of the fish pass causes no change to the most significant hydraulic characteristics (hydraulic depth, velocity, shear stress, as well as flow or stage hydrographs) or to annual sedimentation rates, at the cross sections that are geometrically affected, or at a number of other sites downstream (1m, 3m and 25m downstream) that were chosen for analysis. It is likely that this is a result of the ineffectual representation of the fish pass within the model, rather than the true absence of effects, therefore, the results offered by the model cannot be reliably utilised for this specific application.

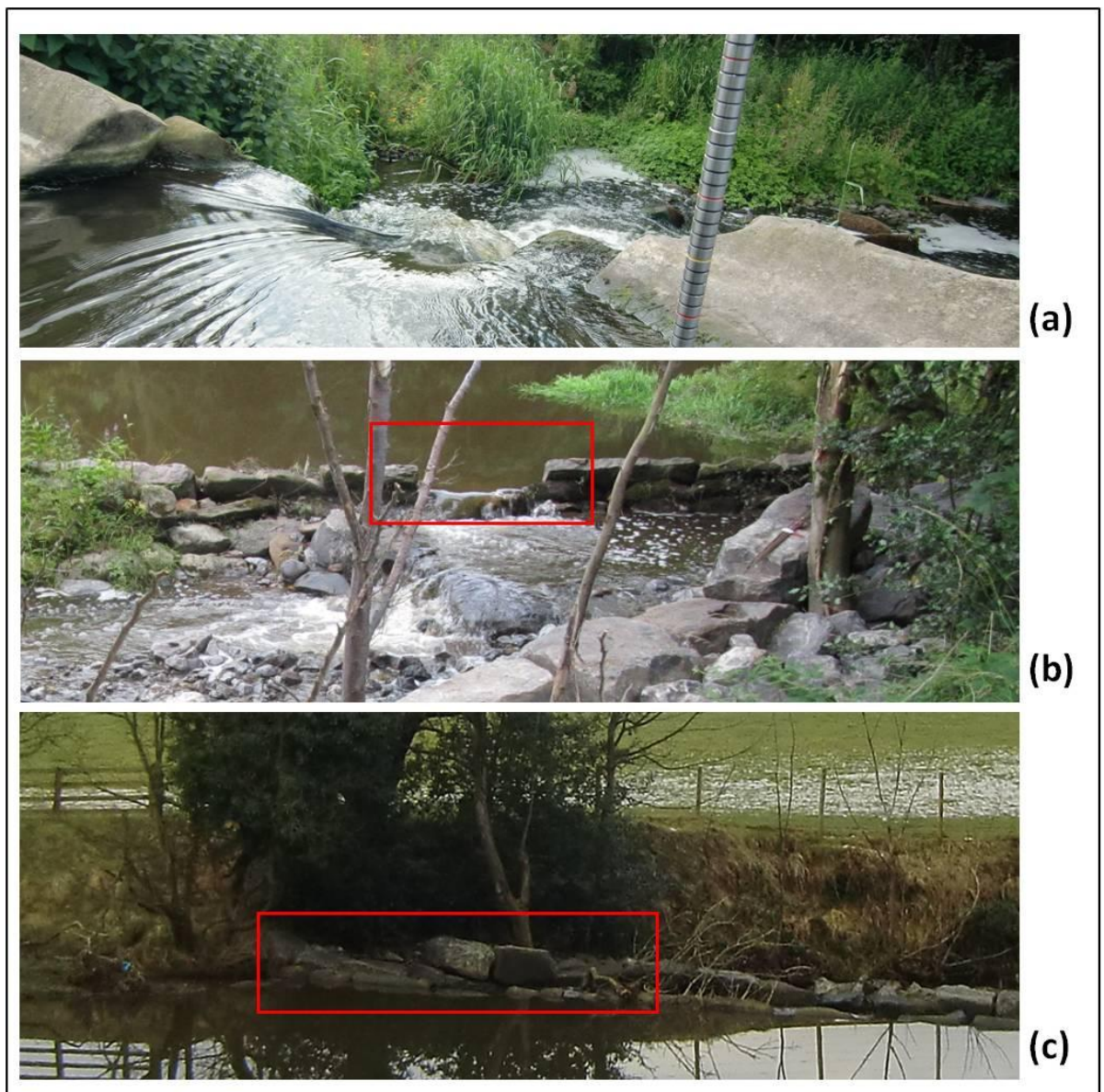


Figure 8.8 Weir structure (a) before restoration (looking downstream); (b) during restoration, with area of gap decreased, (c) with restoration complete, area of gap reduced and top height of weir elevated around gap to direct flow through the fish pass

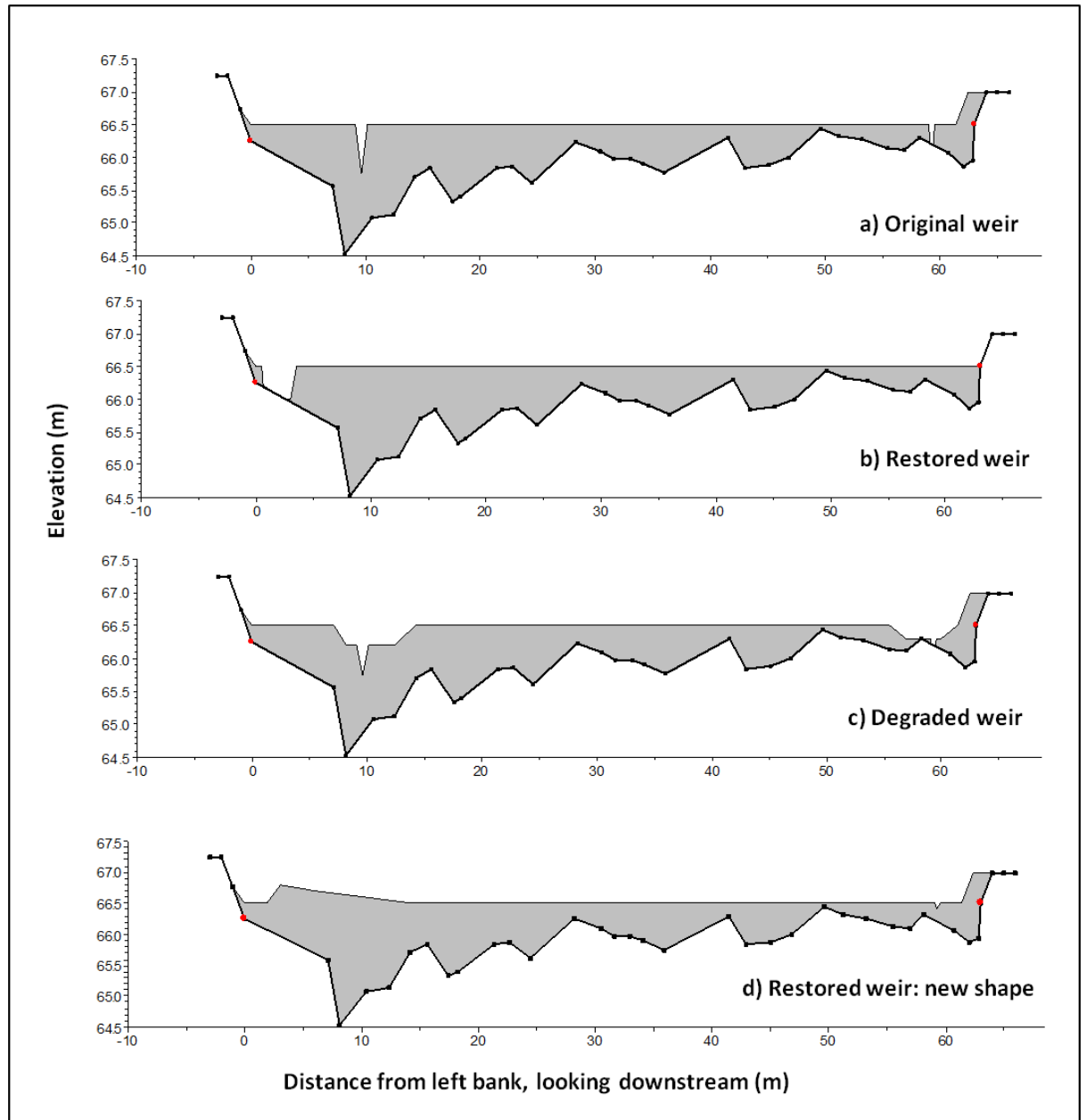


Figure 8.9 Actual restored weir profile (d) compared with original (a), hypothetically restored (b), and hypothetically degraded (c) profiles. Actual restored weir profile was based on dGPS data and discussion with competence group members

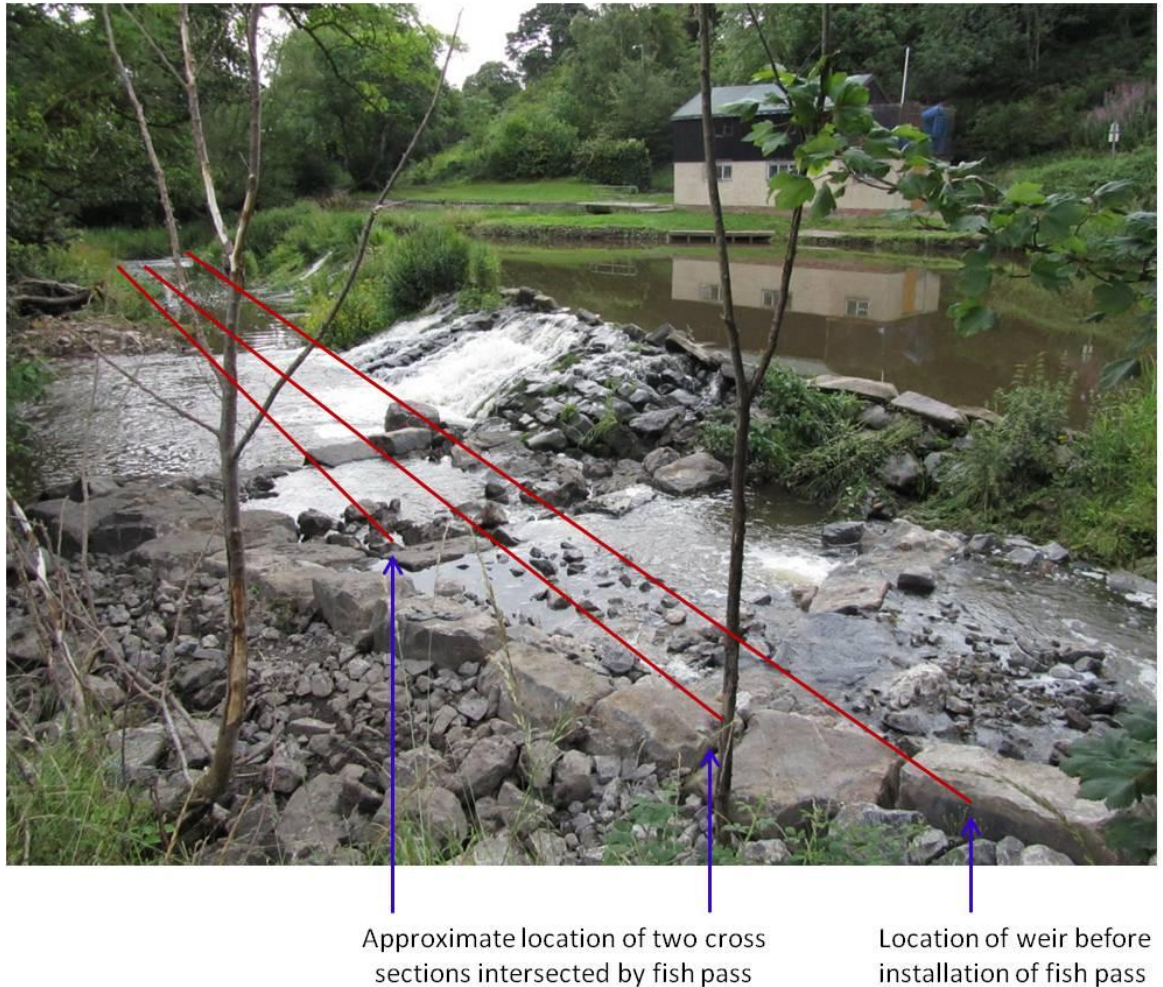


Figure 8.10 Positioning of weir and the two cross sections immediately downstream, prior to fish pass installation

The predicted impact of the redesigned weir shape (see Figure 8.9) on water level immediately upstream of the weir is illustrated in Figure 8.11. It is evident that with the newly designed restored weir in place, the water surface elevation is higher than with any other weir profile, although only between 0.02m and 0.03m higher than is predicted for the original weir (resulting in a very small increase in flow area of approximately 4%). The overall area of flow immediately upstream of the weir, at peak flow, ranges from 40.17 m² (for the degraded weir) to 46.13 m² (for the actual shape of the restored weir), under the flow hydrograph used for the main predictions (see Figure 7.8), (flow areas are 42.13 m² for the hypothetically restored weir and 44.66 m² for original weir). The degraded and hypothetically restored weirs are shown to reduce the amount of water surface elevation variability over a range of flows. For the original and actual restored weirs, the water surface elevation becomes variable upwards of 2.38 m³s⁻¹ (hour 91 of the event), whereas under the conditions of the degraded and hypothetically restored weirs, water surface

elevation is variable above $1.54 \text{ m}^3 \text{ s}^{-1}$ (e.g. at hour 125 of the event). Immediately upstream of the weir, discharge did not vary under the actual restored weir conditions, when compared to the flow rates experienced with the other weir profiles (Figure 8.12). As observed in the results for the original, restored and degraded weirs, water level and flow rate downstream of the weir were not altered according to weir profile.

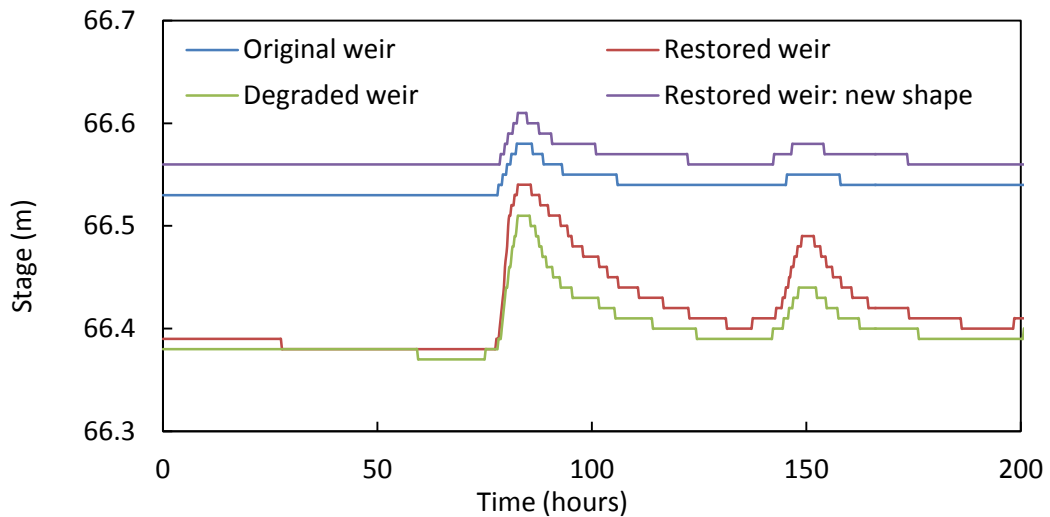


Figure 8.11 Impact of new (actual) shape of restored weir on water level immediately upstream of the weir, compared to impacts of original, hypothetically restored, and hypothetically degraded profiles

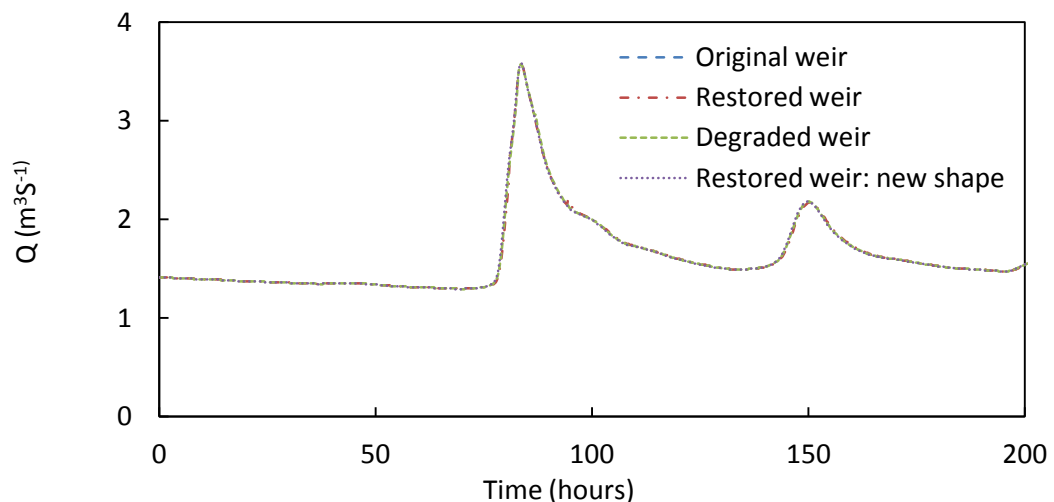


Figure 8.12 Impact of new (actual) shape of restored weir on flow rate immediately upstream of the weir, compared to impacts of original, hypothetically restored, and hypothetically degraded profiles

The effects of the actual restored weir profile, like those found for the other three profiles, propagate for some distance upstream. The impacts felt immediately upstream (Figure 8.11) and 2m upstream of the weir (Figure 8.13a) extended up to 200m upstream of the weir, at which point, the differences in water level due to weir profile begin to converge. Water level at peak flows was similar for all weir profiles (a range of only 0.04m at 200m upstream, compared to a range of 0.1m at two metres upstream of the weir). At 200m upstream, there was still variation in water surface elevation for the original and actual restored profiles at low flows, albeit a small difference. By 1km upstream from the weir, the impact of the actual restored weir bears no significance to water level when compared to all other weir profiles. Again, in agreement with the water level predictions for the original weir, for the actual restored weir profile, the stability of water level that is provided at the site of the structure is lost by 200m upstream, and the stage hydrograph becomes flashier. At all sites (until weir effects are drowned out at 1km upstream), the difference in water surface elevation for different weir profiles is greatest at low flows, and least at peak flows (Figure 8.14)

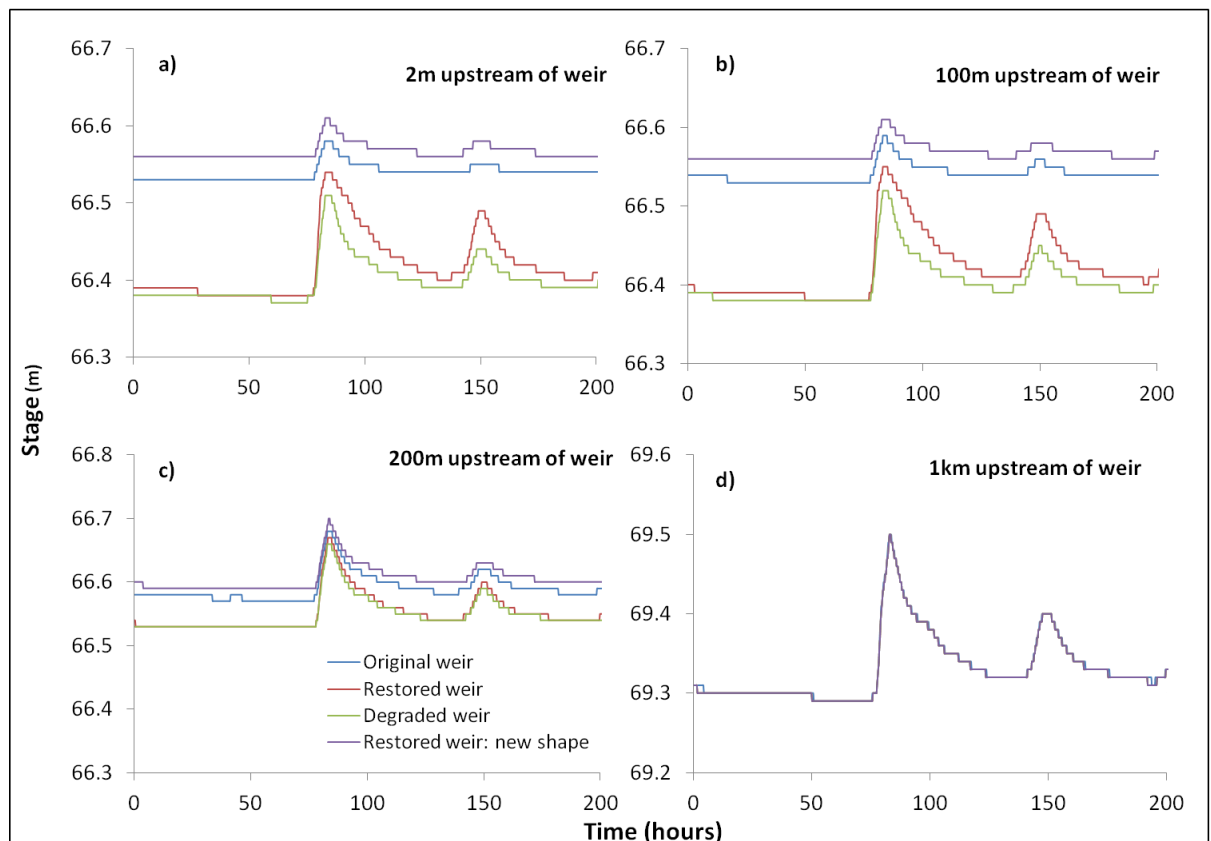


Figure 8.13 Impact of new (actual) shape of restored weir on water level at four sites upstream of the weir, compared to impacts of original, hypothetically restored, and hypothetically degraded profiles. Sites are located 2m (a); 100m (b); 200m (c) and 1km (d) upstream of the weir

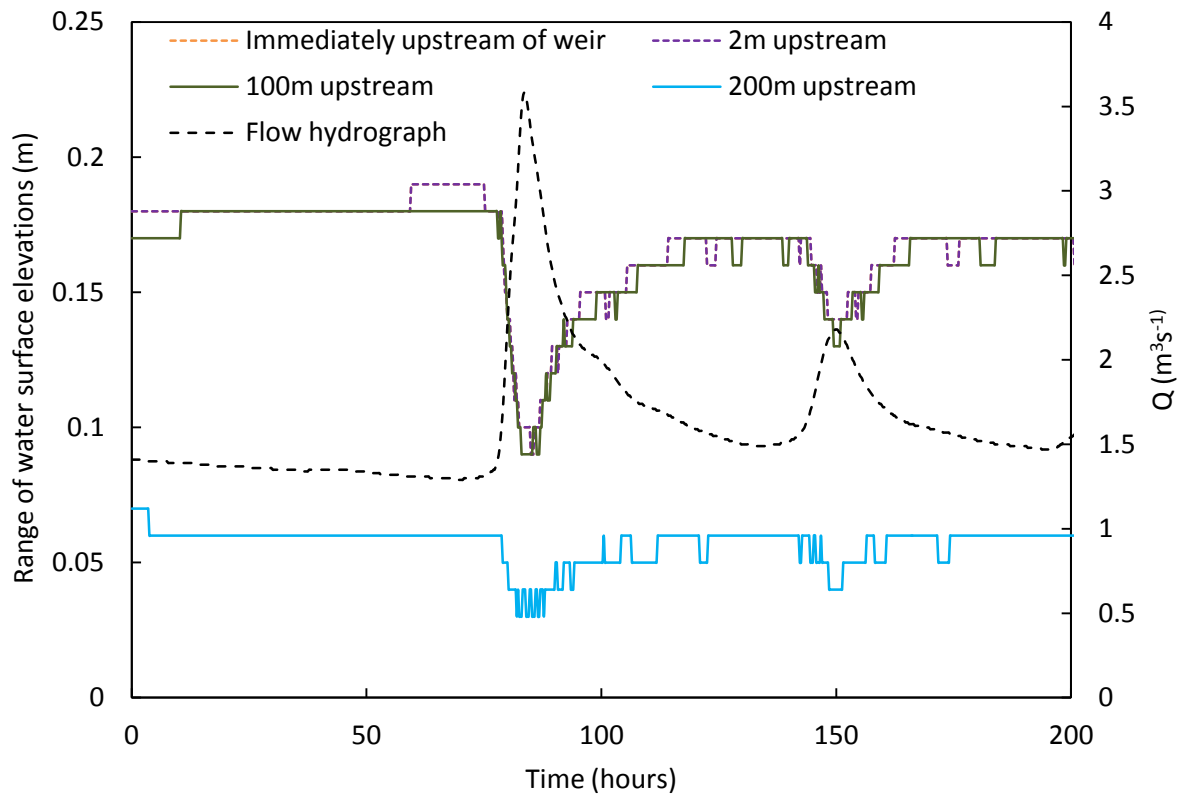


Figure 8.14 Range in water surface elevations (x-axis) between weir profiles at four locations, compared to flow hydrograph (z-axis)

A small amount of erosion of the channel bed upstream of the weir (for five metres) is predicted by HEC-RAS after simulations of a year of flow, and is fairly consistent across the width of the channel (Figure 8.15). Immediately downstream of the weir, the model predicts a significant amount of sediment deposition (0.4m) across the entire cross section, between 4m and 20m downstream, there is no change to bed sediment elevation and further downstream (between 20m and 36m downstream of the weir) some degradation is predicted in the order of 0.04m to 0.1m. However, the nature and magnitude of these predictions apply to all weir profiles, including the actual restored profile.

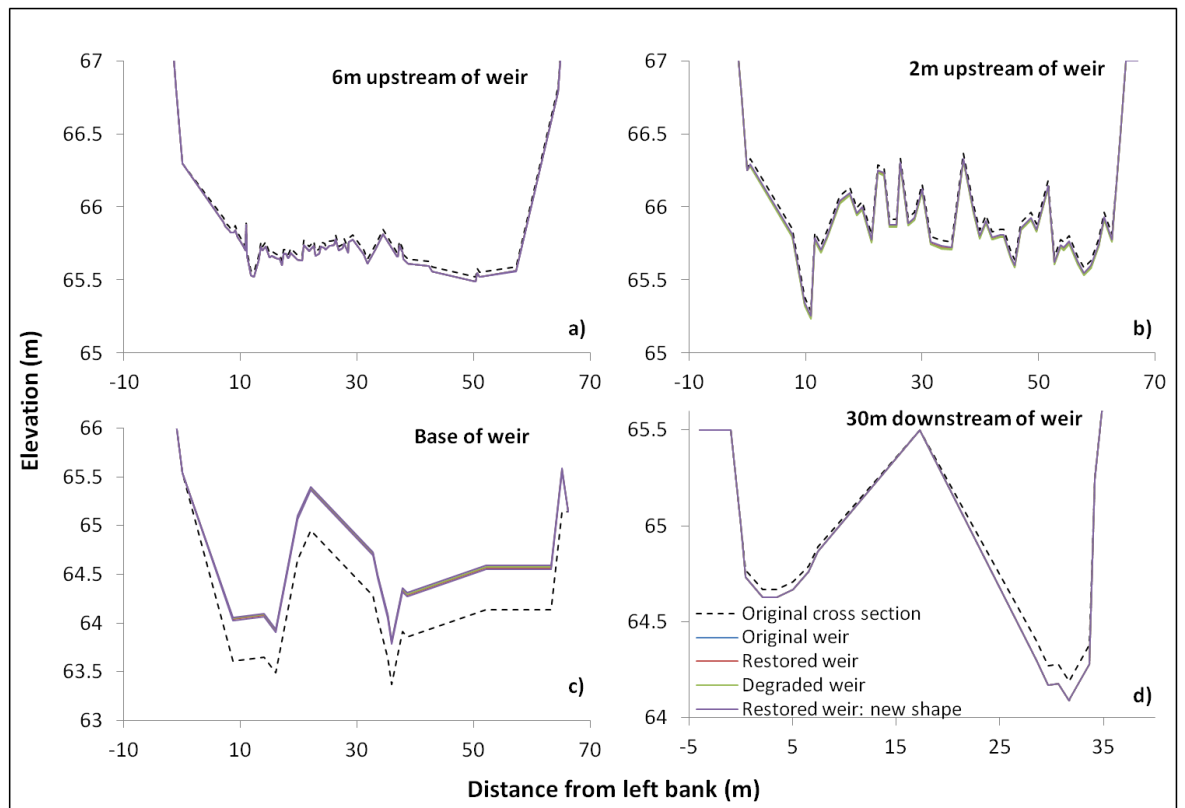


Figure 8.15 Change in cross section profiles as a result of sediment aggradation and degradation, one year after restoration of weir, at four sites: 6m upstream of weir (a); 2m upstream of weir (b); at the base of the weir (c) and 30m downstream of the weir (d)

8.3.3.2 Investigating the impact of a high flow event on water level upstream of the weir

The water level upstream of the weir during a high flow event is highest when the actual restored weir profile is used, and lowest when the degraded profile is used (Figure 8.16), which is concurrent with the findings for the lower flow hydrograph. Other similarities include the convergence of water levels for all weir profiles at the highest flows, greater stability of water level from the original and actual restored weir profiles and the loss of impacts 1km upstream of the weir (Figure 8.17). The range of water surface elevations created by different weir profiles (at maximum flow) immediately upstream of the weir is 0.08m for the higher flow simulation and 0.1m for the lower flow hydrograph. This is a significant range in water surface elevation, given that the hydraulic depth produced by different weir profiles is in the region of 0.7, for the low flow hydrograph, and in the region of 0.8m for the higher flow hydrograph, equating to a change in water surface elevation which is 11.8% and 12.5% of the mean hydraulic depth for the low flow hydrograph and high flow hydrographs, respectively.

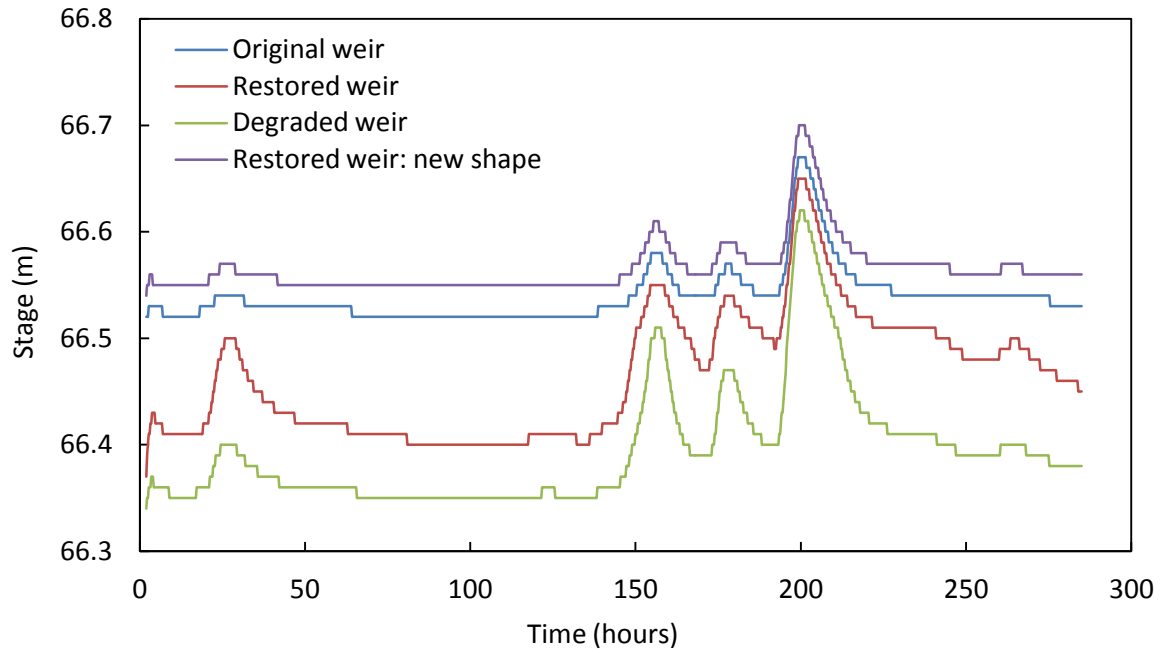


Figure 8.16 Impact of various weir profiles on water level immediately upstream of weir, during a high flow event

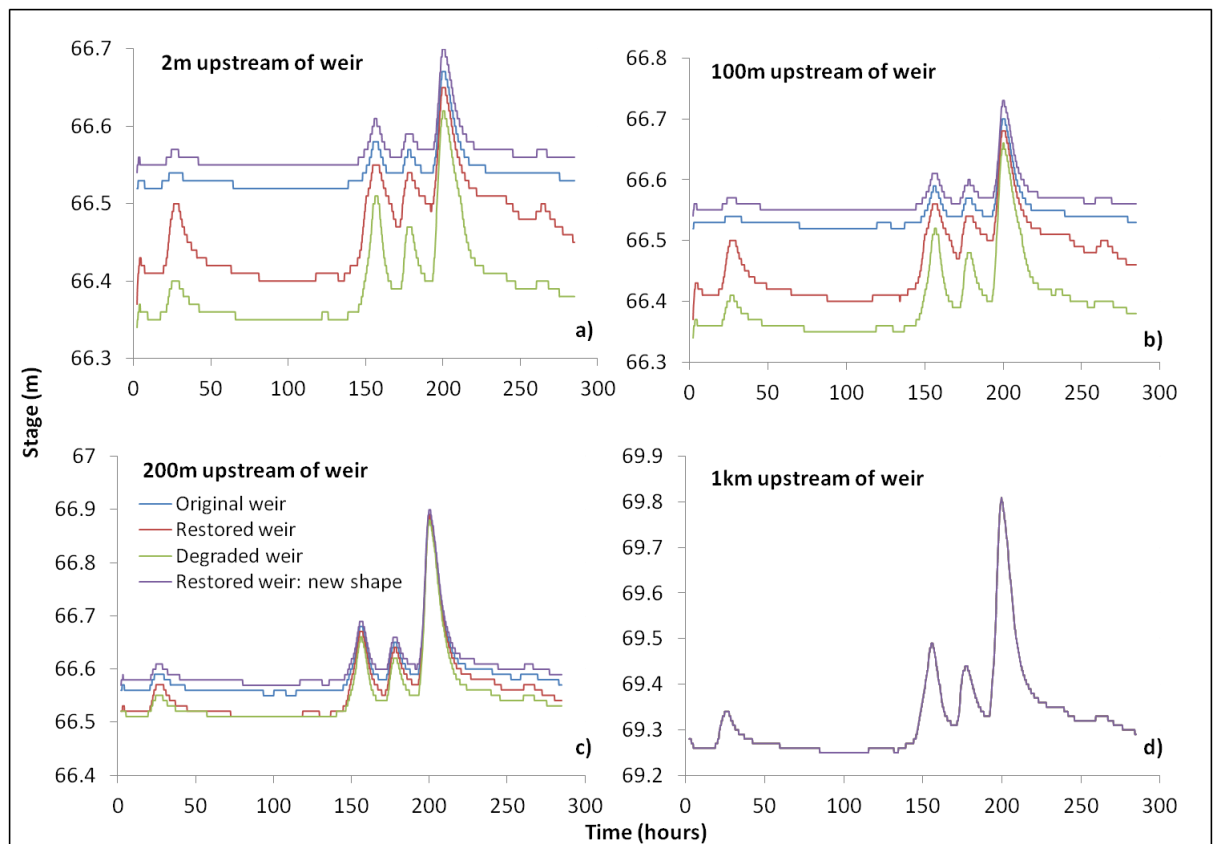


Figure 8.17 Impact of various weir profiles on water level during a high flow event, at 2m (a); 100m (b); 200m (c) and 1km (d) upstream of weir

8.3.3.3 Extent of upstream pool under various weir profile conditions

Flow area in the upstream pool increases with increasing water depth and was therefore affected by weir profile. The position of the water surface elevation on the cross section, relevant to weir profile is illustrated in Figure 8.18 (for the low flow hydrograph) and Figure 8.19 (for the high flow hydrograph). The profile of the actual restored weir caused the greatest water surface elevations and therefore the greatest flow area (for both cross sections studied and both flow events).

The increase in flow area, as a result of different weir profiles, or of high flow events, is limited by the cross section profile at the two points of investigation because of the steep channel banks. However, for boating purposes, a minimum depth is required (this is discussed further in Section 9.3.4.1) and therefore small increases in water depth may be beneficial to those who use the upstream pool.

Table 8.2 summarises the flow characteristics predicted for the cross sections at the boundaries of the boating area, when using the four different weir profiles. The flow area, percentage increase in flow area (when compared to the area predicted when the original weir is in place), maximum channel depth and percentage increase in maximum depth are all greatest when the actual restored weir profile is used (this applies to both cross sections and both hydrographs). The actual restored weir is predicted to increase flow area from that predicted for the original weir by c.3%, which equates to an increase in maximum depth of 2.8 to 3.13% (depending on cross section and hydrograph), while the degraded weir profile is predicted to cause a decrease in flow area of 5.8 to 9.8% and a decrease in depth of 4.4 to 7.3%.

	Low flow event		High flow event	
	6m upstream of weir	50m upstream of weir	6m upstream of weir	50m upstream of weir (m ²)
<i>(i) Flow area (m²)</i>				
Original	51.72	44.09	57.38	49.86
Restored	49.17	41.66	56.12	48.68
Degraded	47.23	39.79	54.03	46.71
Actual restored	53.38	45.69	59.25	51.64
<i>(ii) % increase in flow area</i>				
Restored	-4.93	-5.51	-2.20	-2.37
Degraded	-8.68	-9.75	-5.84	-6.32
Actual restored	+3.21	+3.63	+3.26	+3.57
<i>(iii) Max depth (m)</i>				
Original	1.06	0.96	1.15	1.05
Restored	1.02	0.92	1.12	1.03
Degraded	0.99	0.89	1.1	1
Actual restored	1.09	0.99	1.18	1.08
<i>(iv) % increase in max depth</i>				
Restored	-3.77	-4.17	-2.61	-1.90
Degraded	-6.60	-7.29	-4.35	-4.76
Actual restored	+2.83	+3.13	+2.61	+2.86

Table 8.2 Flow characteristics at boundaries of boating area, under four weir profiles. Including: (i) flow area, (ii) percentage increase in flow area when compared to area created by original weir profile, (iii) maximum channel depth, and (iv) percentage increase in maximum depth when compared to area created by original weir profile

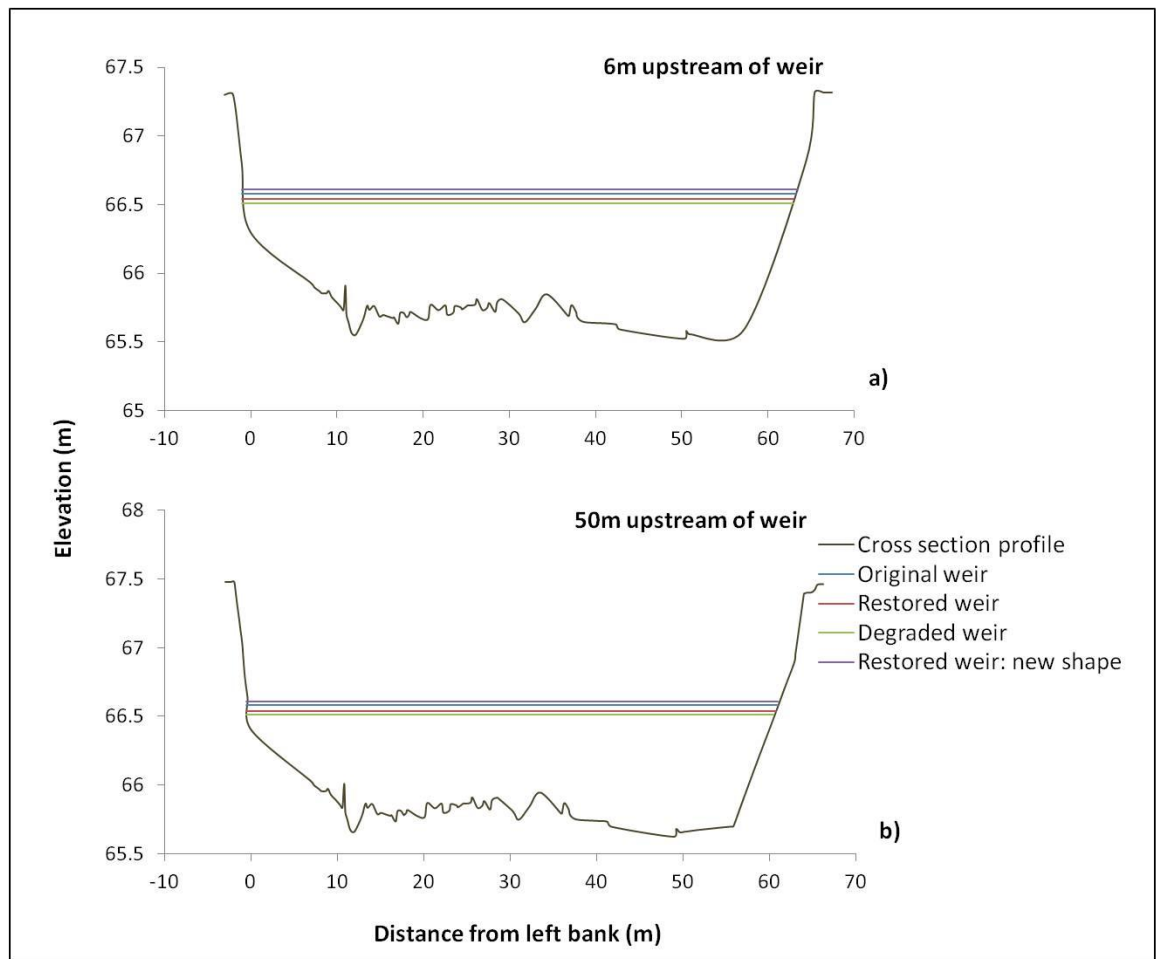


Figure 8.18 Water surface elevations at two sites bordering the boating area for various weir profiles at 6m (a) and 50m (b) upstream of the weir. Water surface elevations are based on standard flow hydrograph used for all analyses.

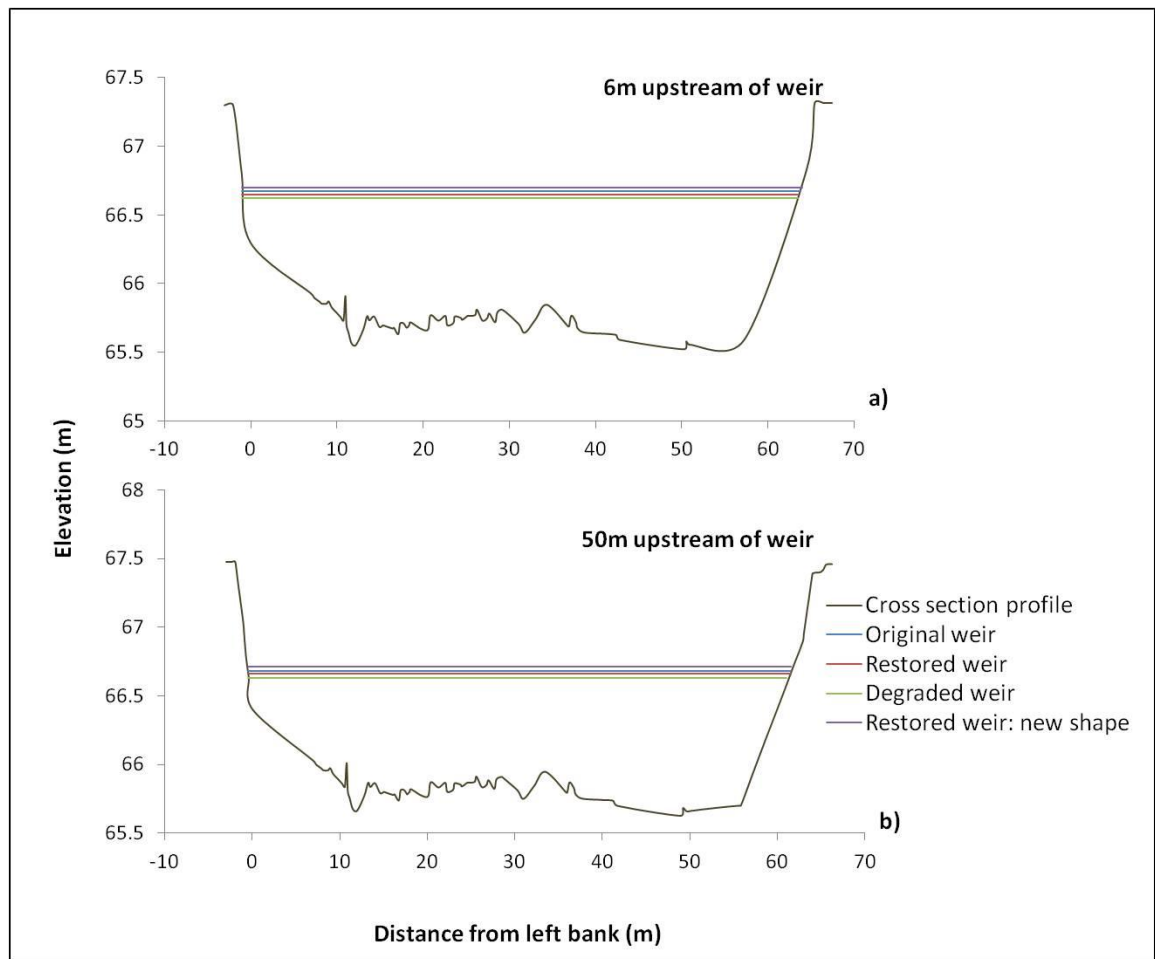


Figure 8.19 Water surface elevations at two sites bordering the boating area, for various weir profiles at 6m (a) and 50 (b) upstream of the weir. Water surface elevations are based on *high* flow hydrograph used in analysis of weir impacts during a period of high flow.

8.4 Process based understanding of the impacts of a changing weir profile, and the position of local knowledge

The model predictions suggest that a number of expected weir impacts will occur at Ebchester which have previously been observed in similar circumstances, including an increase in water depth behind the weir (as observed by Huang and Ng, 2007; Poulet, 2007; Wasserman *et al.*, 2011), creation of a slow flowing pool upstream (Shields *et al.*, 1998; Mueller *et al.*, 2011), decrease in flow depth downstream (Armitage, 1995; Jorde *et al.*, 2008) and sedimentation upstream as a result of decrease in carrying capacity (Kondolf, 1997; Isik *et al.*, 2008; Jorde *et al.*, 2008). All of these effects have been observed by the Competence group members, as outlined in Section 5.2. There are, however, some impacts specific to this site and to the weir profiles used. These impacts are discussed in more detail below.

8.4.1 Effects of weir profiles on flow

8.4.1.1 Weir impacts on upstream flow and water level

The competence group members suggested that the recent increases in the degraded area of the weir were the cause of reduced water levels in the upstream pool and suggested that reducing the size of the gap in the weir would help restore the water level. This was reflected in the model findings. The higher water surface elevations predicted for the actual restored weir profile are explained simply by the change in area of cross section that is affected through the different profile shapes. For example, the hypothetically degraded weir has a flow gap area of 2.9m^2 , while the original weir has a gap of 0.5m^2 . The actual restored profile gap has an area of 0.9m^2 , through which water may flow, *however*, the structure of the weir surrounding the location of gap has been built up so that the new lowest point over which water can flow is at the same elevation as the top of the original weir (see Figures 8.8c and 8.9). The increase in overall area of the channel obstruction combined with the partial increase in top elevation of that obstruction mean that an increase in the volume of water in the upstream pool is possible. This impact propagates upstream for around 200 m, at which point the gradient of the bed increases slightly (from 0.002 to 0.0026), the banks become constrained by steep, vegetated slopes and the channel narrows. Channel gradient is known to contribute to the determination of the extent of a backwater behind weir structures (Li *et al.*, 1981; Salant *et al.*, 2012) and in their study, Salant *et al.* (2012) found backwaters to extend to the next upstream weir because of the low channel gradient.

As outlined above, the backwater (and all the effects of the weir) diminish with distance upstream. Extremes in flow are buffered by the storage effect created by the weir structure (Batalla *et al.*, 2004; Brown and Pasternack, 2008; Isik *et al.*, 2008) but as slope and channel form change upstream of the weir, the potential area for water storage, and its associated characters, diminish. Walker *et al.* (1992) and Walker and Thoms (1993) suggest that the short term (daily) changes to velocity and flow rate caused by low-head weirs, are also short in terms of spatial impact, because of the low magnitude of the effects. Decrease in the magnitude of impacts with distance upstream may also be linked to sediment deposition processes. As flow faces resistance from the weir structure, it loses energy and deposits its sediment load, the river bed upstream of the weir may be elevated and therefore water surface elevation may increase (Walker, 2001) until the top of the weir is reached (this has been observed by M5, who discusses the depth of the main pool (exceeding two metres), but immediately behind the weir, can be as low as 0.1m). Most sediment deposition occurs close to the weir structure and the degree of bed elevation and

associated water surface elevation decrease with distance from the weir. This process is also limited by channel slope (and therefore flow velocity and shear stress), but over time the area of water surface elevation may extend upstream as a result of free flowing water entering the slow flowing pool and sediment being deposited sooner.

There are some instances in which different weir profiles produce the same water surface elevation predictions. The hypothetically restored and degraded profiles result in roughly the same water surface elevation for any stage below 66.4 m (Figure 8.1), despite the overall gaps in the weir varying between 1.25 and 1.9m², respectively. This may reflect a base flow in the river (the discharge at this point is 1.5m³S⁻¹), which is present regardless of weir shape.

The effect of weir shape is lessened with distance upstream of the weir and is non-existent by 1km upstream. However, the depletion of effect over distance occurs gradually, beginning with peak flows, in other words, the impact of the weir profile at low flows propagates further upstream than high flows. Proportionally, at low flows the weir and the various gaps in the weir have a greater impact of resistance on flow than they do at high flows. Furthermore, at high flows there is potential for increased velocity which will overcome friction and move the flow downstream more quickly.

The higher local 'baseflow' for the pool, that is provided by the original and actual restored weir profiles (because of the reduced size and increased elevation of the gap in the weir) results in less flashy stage hydrographs for these profiles, than for the degraded and hypothetically restored profiles (e.g. see falling limb of flood peak at 100 hours in Figures 7.16 and 7.17, as well as 8.11 and 8.13). This may be attributed to the stabilisation of flow as a result of dams and weirs (Li *et al.*, 1981). In the case of Ebchester, the stabilisation can be explained by the variation of area available for flow through the weir in different profiles, with the smallest areas of degradation causing the highest water levels and baseflows and as a result, small fluctuations in flow make proportionally smaller differences to the overall volume of the pool. This effect diminishes with distance upstream of the weir (compare falling limb of flood peak at around 100 hours, 2m upstream and 200m upstream in Figure 8.13), where flashiness increases at all but the lowest flows, as a result of the deteriorating impact of the weir on flow with distance (discussed above). This may be further compounded by the narrowing of the channel with distance from the weir, meaning that smaller changes in discharge will cause relatively bigger changes in water surface depth (as described by M5 in Section 5.2.4.2).

The model predicted that changing the weir profile would cause differences in water surface elevation upstream of the weir. However, it also predicted that discharge (i.e. the flow hydrograph) would be virtually unaffected and this outcome was also predicted by a number of the Competence group members, who suggested that flow would be relatively unaffected once the greater capacity pool provided by a restored weir, was filled (M5, Section 5.2.4.1). This may be as a result of the relationship between velocity and flow area (see Equation 6.3). As velocity decreases, flow area (and therefore water surface elevation) increases to accommodate a certain volume of flow within a cross section (i.e. conservation of mass, as demonstrated through Equation 6.4). Therefore, an increase in flow area combined with a proportional decrease in velocity would cause no change to discharge for a given cross section at a given time. In order to maintain a constant flow rate, the model adjusts water surface elevation to accommodate the different levels of resistance provided by the different weir profiles. For example, the weir profile with the lowest water surface elevation (and flow area), has the highest velocities (0.088m/s for peak flow), while the profile with the highest water surface elevations has the lowest velocities (0.077m/s for peak flow) and when velocities are multiplied by the flow area for each time-step of the hydrograph, the result equates to the discharge value, which is the same (+/- 0.2m³s⁻¹) for all four profiles (see Figures 7.18 and 8.12).

The impacts of weir profile, while causing some significant changes to flow area and depth when compared to those predicted for the original weir profile, are proportionally small, ranging from 2.2 to 9.75% of the flow area/depth for the cross sections analysed (Table 8.2). The area of the weir open to allow flow to pass through is a very small proportion of the total weir area (see Figure 8.9) and therefore changes made to this area will cause subtle changes in upstream water depth and flow area. The presence of a barrier to flow in any form is what has the most significant impact on flow upstream of the structure, and this is reflected in characteristics such as the presence of the pool, the channel width, sediment depth/composition and flow velocity (as discussed in Section 8.4), and in the absence of major changes to these features under varying weir profile conditions. Li *et al.* (1981) suggest that split dams should be used to ameliorate the impacts of a full dam (for example sediment accumulation and slowing of flow, which is noted by the Competence group to occur during periods of elevated flow, leading to a variable bed elevation behind the weir structure). It is believed that while Ebchester weir causes many of the outcomes expected from any form of river impoundment, the gap in the structure serves to create conditions similar to those of a split dam and while there is evidence of fine sediment accumulation, and a significant upstream pool in which water is slowed and surface elevated,

these impacts would be more pronounced if the weir was fully blocked, and indeed, may prove to be so in the years to come as the river adapts to the restored weir structure.

8.4.1.2 Weir impacts on downstream flow and water level

The effects of the weir on downstream water level and discharge, according to the model predictions, are negligible. Once the river has adjusted to the weir structure (e.g. development of an upstream backwater, upstream sedimentation and shallow, fast flowing reach downstream, with armoured bed), the area of degradation, and the diversion of flow towards that point in the weir effectively creates a new primary flow route within the river, so that the majority of flow passing over the weir is concentrated into one location. While water surface elevation and flow rate respond to varied flow over time, the change in shape and area of the gap in the weir for different profiles is not significant enough to cause changes in flow elevation. This may be aided by the very deep pool and very wide channel already established downstream of the weir, in which small fluctuations in flow are insignificant. Furthermore, once the upstream pool has 'filled' in response to a new weir profile, the same volume of water will pass through it as was experienced with the original weir profile (as discussed above, 8.4.1.1). The actual restored weir has led to a slight increase in the water head height which may be expected, over time, to lead to a deepening of the downstream pool (also highlighted by M6, Section 5.2.4.1). However, the weir at Ebchester is over 300 years old and the downstream river bed is armoured with cobbles (discussed by Conesa-Garcia and Garcia-Lorenzo, 2008; Salant *et al.*, 2012), meaning that a very large increase in shear stress would be required to change the bed structure (Knighton, 1998, 311). The model does not predict that this would happen within one year of the weir restoration, even without an armoured bed.

8.4.2 Effects of weir profiles on sediment dynamics

8.4.2.1 Model predictions of weir impacts on sediment dynamics

The model suggested that changing weir profile would have negligible or no impact on sediment dynamics and bed elevation downstream of the weir. This may be linked to the lack of change effected in flow rate and water surface elevation downstream of the weir (as discussed above) in response to changing weir profile. If the hydrological controls experience no change, then there is nothing within the model to drive a change in sediment transport and distribution. Although the effects of the weir profile are limited, the impact of the weir itself is evident within the channel. Figure 7.25 illustrated how the magnitude of bed elevation change was greatest around the area of the weir, when compared to all other changes predicted for the catchment. Therefore, the following paragraphs focus on analysis of the predicted bed elevation changes in response to the

general presence of the weir, and then the observed characteristics within the channel and how they relate to expected weir impacts, as cited by other researchers.

The model used in the sediment dynamics analysis predicted that there would be a small amount of degradation upstream of the weir. This is contradictory to many of the studies of the impacts of weirs (e.g. the widening of a channel reduces velocity and shear stress (Tiemann *et al.*, 2004), which leads to sediment deposition (Kondolf, 1997)), but in agreement with the observations of some Competence group members who note that scour occurs behind the weir during high flows (Section 5.2.4.3). It is believed that in this case, the large storm which occurred in September 2008 (the self-selected reference event for most of the Competence group members in discussion of flood magnitude) and the proportion of fine sediment present in the upstream pool may have resulted in the model prediction of the flushing of some of this sediment. The change in cross section profiles occurs on the day of the flood event (8 September 2008) and is the only change to the bed sediment over a whole year of simulations. The large increase in bed elevation immediately downstream of the weir is also contradictory to published observations and expectations (i.e. downstream scouring of the bed: Walker, 2001; Tiemann *et al.*, 2004; Salant *et al.*, 2012), but may be explained by the deposition of sediment carried over the weir in the storm event and becoming trapped in the downstream pool (where there is a negative slope, which will greatly increase critical shear stress for the mobilisation of particles in that location, Gurnell, 1997; Knighton, 1998, 107). A similar effect was described by Walker (2001) in which a low-head weir was swamped with gravel during very high flows, leading to the filling of downstream scour pools. Huang and Ng (2007) also suggest that elevation of flow immediately downstream of a weir may be reduced if water passes through at an accelerated rate. This may also mean that deposited sediments cannot be scoured out. Again, there is only one change to bed profile during the year of simulations, and this occurs on the day of the flood event.

Further downstream of the weir, there is no change to bed elevation as a result of sediment aggradation or deposition, for 16 m, after which, there is a stretch of around 16 m in which all cross sections experience some degradation. This is more in line with the expected impacts of a low-head weir and is likely to be caused by the kinetic energy gained by the flow from the fall height. A reduction in sediment availability is frequently cited as a factor leading to bed degradation downstream of an obstruction (Isik *et al.*, 2008; Jorde *et al.*, 2008). Most of the degradation predicted by the model occurs on cross sections within the already lowered bed (or the pools, as described by Richards, 1976; Knighton, 1998). Clifford (1993) and Sear (1993) suggested that pools are more open structures than riffles, with potentially lower entrainment

thresholds and it has been suggested that at flows of a magnitude capable of transporting sediment, it is pools, rather than riffles, that have the highest shear stress values (e.g. Keller and Florsheim, 1993). In this way, degradation may occur in pools, with sediment deposited in riffles, thus maintaining riffle-pool sequences (Knighton, 1998, 196).

It should be noted that only the highest of flows (over a number of years, not just within one year) were sufficient to cause a change to bed elevations and that the flood event was far more effective in creating erosive energy than the weir head itself. The shear stress immediately downstream of the weir at the peak of the flood is 6.86 N/m^2 , which is almost five times greater than any other shear stress experienced in the year 2007-2008 (the next highest shear stress is 1.4 N/m^2 and the median is 0.12 N/m^2).

What the model cannot predict is the distribution of sediment aggradation or degradation across a channel (a 2D model would be required to represent this accurately and is beyond the scope of the current study). Therefore it is possible (and likely) that the change in bed elevations would in reality be concentrated into a certain area of the cross section. For example, immediately downstream of the weir, there may have been extreme levels of erosion as a result of the high volumes of water passing over the weir, and this sediment may have deposited elsewhere in the cross section, resulting in an overall increase in bed elevation, as was predicted.

8.4.2.2 Observed weir impacts on sediment dynamics

Despite the absence of effects from different weir profiles, the presence of the weir itself has clearly caused alterations to sediment dynamics and a number of these are evident from the cross section and sediment size distribution data collected in the field. There is a local elevation of the bed upstream of the weir, which lessens with distance further upstream (described by Walker, 2001). This is caused by the deposition of sediment being most strongly concentrated at the point of resistance (i.e. the weir) as transport capacity is reduced (Mueller *et al.*, 2011). The sediment size distribution behind the weir (the first 4m) is dominated by relatively fine sediment (smaller than gravel, see Figure 7.4), which is noted to be characteristic by Mueller *et al.* (2011) and the characteristic loss of riffles and pools (e.g. Jowett and Duncan, 1990; Salant *et al.*, 2012) upstream of weirs is evident, and compliant with the observation of Knighton (1998, 194), that such sequences are rare in channels dominated by sand and silt (although M5 of the Competence group does note that despite the fine sediment accumulation, there are areas of depression in the upstream pool, perhaps remnants of a riffle-pool sequence, over which a layer of fine sediment has been deposited at a depth which is sufficient to drown out riffle features, but not fully in-fill pools). However, immediately upstream of the weir, the sediment size profile is skewed by the

presence of a number of large rocks, boulders and fabricated materials, which are believed to be from the weir itself as degradation has occurred and from the boathouse structures on the river bank, which have been replaced around three times in the last 100 years (according to the Competence group). Large boulders may also be moved downstream in very high flow events but if they cannot be physically lifted over the weir, would be deposited just behind it.

At the base of the weir, there is a deep pool at the left hand side of the channel (looking downstream) and another pool on the right side, which is shallower. Between the two is an area of very shallow water, in which deposition occurs. This is concurrent with the locations of the weir degradation (and therefore the greatest rates of flow). The primary gap is located on the left side (looking downstream) and a smaller gap is present on the right side. Flow upstream of the weir is directed primarily to the left side (which is the shortest route to the weir), with some overspill on the right, and still water in the centre. The weir rarely overtops in the middle reaches, evident through the dense vegetation growing in the centre (as discussed by the Competence group, see Section 5.2.6.2). Shallow, fast flowing water will be found downstream of weir structures (Tiemann *et al.*, 2004) and has greater kinetic energy and shear stress which makes it more efficient at displacing and transporting sediment particles, and it has been suggested that the shape of a partial weir (or location of a gap in a weir) will determine the location of scouring (Hey, 1992, 100). The depth of the main pool increases for about two metres with distance downstream of the weir, as the channel narrows slightly, before rising, entering two more depressions, and then levelling out to a riffle-like profile (see discussion of riffle-pool systems above).

Channel morphology responds more slowly than flow, to changes in channel form and to changes in flow characteristics. Petts (1980) suggests that following the installation of dams, channels may take years or decades to adjust, but once they do, they become stable, and once stable, with bed armouring and channel bars, channel adjustment may take centuries (Kellerhals, 1982, 698). For example, armouring is commonly cited as an impact of channel impoundment (Li *et al.*, 1981; Petts, 1980, 1984; Kondolf, 1997; Conesa-Garcia and Garcia-Lorenzo, 2008), as high-energy flows with low sediment supply rates scour fines out of the bed and leave a bed with sediment sizes larger than usual (Kellerhals, 1982; Tiemann, *et al.*, 2004; Im *et al.*, 2011; Salant *et al.*, 2012) which protect underlying sediment from erosion and limit the ultimate depth of incision that is possible (Dietrich *et al.*, 1989). This results in an armouring of the river bed. The reduction of channel slope or increase of roughness as a result of degradation downstream of a weir can cause hydraulic conditions to reach a threshold beyond which further erosion is limited (Knighton, 1998,

310), thus stabilising the bed. It is likely that the river bed at Ebchester has reached a point of stability, given that the current dominant conditions have existed for a number of centuries. Therefore, model predictions should be considered with care as the model cannot account for the current state of the river, in terms of bed-structures such as armoured areas.

8.4.2.3 Weir impacts on ecology and habitat

Impacts on ecology and habitat could not be investigated in depth within the scope of this study. However, there is anecdotal evidence from the Competence group to suggest that the weir acts as a barrier to diadromous fish species (also discussed by Baumgartner, 2007; Lucas *et al.*, 2009) because of their absence in upstream areas, but a presence within metres of the weir (downstream) so significant that the pools in the reach are a popular angling location. The slow flowing, upstream pool is reflective of the lentic conditions described by Chick *et al.* (2006), although the specific effects of this on fish populations and habitat cannot be speculated here. However, some of the positive aspects of low head weirs that have been suggested can be found at Ebchester, such as the development of fast flowing, well aerated plunge pools formed by increased water head heights and areas of shelter provided in pools (e.g. Salant *et al.*, 2012). There is also anecdotal evidence that the upstream pool has affected the macroinvertebrate populations ("*there are now many mayfly hatching the area [the upstream pool], which are a silt dwelling species*" M6, CG1), reflective of Tiemann *et al.*'s (2004) observation that flow characteristics can affect abundance and evenness, with deep, slow flowing sites causing a decrease in species evenness.

8.4.3 Causes of changes in channel morphology and vegetation growth

Kellerhals (1982, 698) notes that mid-channel bars may develop as a result of reduced carrying capacity downstream of a dam or weir. If the water level rarely inundates the bar, it will become vegetated, with suspended load and windblown sand being deposited on the bar, higher than normal flow levels can reach, thus further stabilising the bar which then grows large proportional to the channel that it divides. The bar at Ebchester appears to have undergone such developments, being populated by high levels of successive vegetation (a number of established trees and thick shrub), as well as a depression in the centre, showing that the sides have continued to build over time (as noted by the Competence group, and documented in historical photographs, see Figure 5.1). Similar processes have been observed in a number of locations including the River Tone, UK (Gregory and Park, 1974), the Peace River, Canada (Kellerhals, 1982, 698) and Trinity River, USA (Kondolf, 1997).

The presence of vegetation is not only encouraged through increased surface area available for colonisation, but in the lack of periodic control, which in unregulated streams occurs as stripping by flood events, but downstream of dams and weirs is limited or absent (Kondolf, 1997). The Competence group noted (and it was identified through a number of historical photographs), that until 40 years ago, there was no dense vegetation on the mid-channel bar, the river banks or the weir itself (see Section 5.2.3.2).

The timing of the observations made over the development of the mid-channel bar and the encroachment of vegetation raise questions over the cause of these processes. Anecdotal evidence and historical photographs indicate that changes began in the 1970s, while Ebchester weir has been in place for over 300 years. For the first 200-250 years, some of the flow was diverted from the channel to the Mill Race which will have reduced the volume of water passing over the weir. However, the Mills have not been operational for some time, and the Mill Race is known to have been dry (approximately) for the last 30 years. The single largest change to the River Derwent in the last 100 years has been the impoundment of the river, 19 km upstream of Ebchester, at Derwent Reservoir. This increased low flows (Q95) by around 57% (see Table 5.1), but reduced high flows (i.e. the flows responsible for stripping of sediment), to 29% of the pre-impoundment rate (for Q5). This statistic has been anecdotally supported by most Competence group members who have observed reduced flood peaks and vegetation stripping events in the last 20-30 years or so, and attributed this to the reduction of high flows, caused by the dam closure (see Section 5.2.3.2 for full discussion). Therefore, it appears that Derwent Reservoir, although some 19 km upstream of Ebchester, has had a significant impact on the river at Ebchester, and it is the effects of the reservoir, combined with those of the weir (e.g. reduction of carrying capacity and limitation of sediment supply, both on a local and catchment scale), that have caused the changes to the bar morphology and vegetation. These effects cannot be quantified due to the lack of monitoring data for the catchment, but the knowledge developed within the competence group allows the group to understand how the area around Ebchester has changed within (and just before) living memory.

8.5 Finalised model predictions and chapter conclusions

This chapter has presented the process by which the preliminary model results were introduced to the competence group and deliberated in order to further develop the modelling approach and generate a knowledge and understanding of the river and the potential impacts of varying weir profiles. The preliminary model results were discussed with the Competence group (Section 8.2)

and the important assumptions and uncertainties were deliberated among the group, to ensure a unified understanding of their implications. This aspect of the process highlighted the initial difference in expectations possessed by various group members. Following the discussion of preliminary results (Section 8.3) and model demonstration, a set of potential revisions and developments was established, based on the joint knowledge and response of the group (Section 8.3.2). The proposed revisions were prioritised and some were selected for further model development, these included amending the shape of the restored weir profile; investigating the impact of a high flow event on the scenarios already examined and further analysis of the usability of the upstream pool in response to various weir profiles. The revised findings, comments on group expectations, and a note on accountability are summarised below.

8.5.1 Summary of findings

While remembering that the model predictions are not fully accurate, and that the performance in sediment dynamics simulations cannot be quantitatively evaluated, the model development process produced a number of predictions concerning the effect of various weir profiles for the River Derwent at Ebchester. The results suggest that changes in weir profiles will have the most profound effects on water level (and flow area) upstream of the weir, with the actual restored profile causing the highest water surface elevations, an increase of 3.21% in flow area and 2.83% in depth, compared to the original weir profile (for the low flow hydrograph, 6m upstream of the weir). In terms of one of the main research priorities for the EWRG, this result suggests an increase in flow depth from 2.83m to 3.13m within the boating area. The results suggest that not only would weir restoration increase the depth of flow in the upstream pool, but, if left to deteriorate further (as predicted by the Competence group), the profile of the weir could reduce flow depths by around one metre (at low flows, 6m upstream of the weir). The input of the Competence group members was vital in identifying that the initial model predictions did not match the observations of the effects of weir restoration, and in developing the model to make more accurate representations. The predicted effects of the changing weir profiles were similar in nature when applied to a high flow event.

Downstream of the weir, changes in flow rate and water surface elevation as a result of weir profile alterations were negligible and it was concluded the presence of the weir itself was the dominant controlling factor on downstream flows.

Although the sediment component of the assessment could not be validated in traditional scientific terms, knowledge generated with the Competence group meetings served to assist the group in understanding the reasons for the unexpected model predictions of upstream bed

degradation and downstream aggradation (immediately downstream) (see Figure 8.15). In turn, and buoyed by the aforementioned interpretation of sediment model results, the model predictions helped to develop an understanding among the group of how the bed may respond to the presence of a weir within the pool-riffle sequence (i.e. degradation of up to 0.1m, 30m downstream of the weir, Figure 8.15). It was, however, concluded that the predicted bed elevation changes may be moot, given the long-standing position of the weir and the likelihood that armouring and colonisation have resulted in a stabilised channel for many years (Sections 8.4.1.2 and 8.4.2.2).

The predicted change to the area of the upstream pool as a result of varying weir profiles is summarised in Table 8.2. The model outputs suggest that the actual restored weir profile would increase the capacity of the pool, when compared to the original weir profile, and that, if allowed to deteriorate, weir degradation may cause a decrease in depth of up to 7.29%, when compared to the original weir profile. Through the deliberation of the vegetation removal results (see Section 7.3.3), it was concluded that any amateur maintenance of bar and weir vegetation would be futile, as a result of the subtle impacts this is predicted to have, and the observations of the rate of vegetation re-establishment following manual removal.

8.5.2 Group expectations and the role of experiential knowledge

During the presentation and deliberation of preliminary results, the existence of a range of expectations among group members was identified. For example, some group members considered the validation statistics to be unsatisfactory (Section 8.2.2) (e.g. Nash-Sutcliffe score of 0.89), despite that score being cited as a fairly strong prediction within hydraulic modelling literature. Additionally, there was some degree of questioning concerning the data used for boundary conditions (primarily the method by which stage data are converted to flow records by the EA), as well as the lack of functions available to account for catchment conditions such as soil moisture content and current river levels at the time of a storm event. Questioning these aspects allowed the competence group to achieve two outcomes. First, the range of expectations was levelled through discussion of acceptable levels of uncertainty within different groups. Second, I was able to gain an understanding of the factors of major importance to the group and to develop an appreciation of why it is common for 'non-scientists' to require a single and clear number, answer or solution to a problem (it is easier to digest and to use, e.g. as a lobbying tool). Third, the group were able to understand the reasons for a range of results often being necessary, and the necessity of some quantification of uncertainty (and the unlikely event that a result would be absolute – because it is a prediction and not an observation). Establishing a joint understanding of the acceptable levels of uncertainty (to all members of the group) was imperative in order to

ensure the deliberation process was carried out with a fair perspective from all parties, which is not dominated by rejection of the predictions that are available, but open and constructive discussion was allowed to proceed.

The importance of the knowledge provided by various group members (at all stages) was key in developing a heightened understanding within the group, both of what the model predictions meant for the river, and of the current and potential implications of various weir profiles. Many of the observations provided by group members at the outset were seen to be reproduced in the model outputs, or in the interpretation process. The most notable example of this, is in trying to understand the reasons behind the unexpected prediction of overall scouring upstream of the weir, and deposition downstream. It was the observation of one group member that large flood events scour fine sediment from the upstream which led the group to look in more detail at the flood event within the simulation.

As a result of experiential knowledge, the questioning of data and processes, and group deliberation, this process was effective in developing the model into a tool which is more scientifically and socially robust. The relative success of the processes of knowledge production and participation will be discussed fully in Chapter Nine.

8.5.3 A note on accountability

A general copy of the model is retained only with the author, but may be consulted, should further questions arise. However, as mentioned at the outset of the model application process (Section 7.3), it was not the intention of this study to provide stand-alone modelling results which could be used independently as a tool to bargain for the restoration of the weir. Only through a truly deliberative and participatory process, could a thorough understanding of the systems at play within and around the River Derwent at Ebchester be developed. In terms of accountability, therefore, one individual is not responsible for the knowledge produced, because it has been produced not by an individual, but collectively, within the group. One of the dominant features of co-produced knowledge outlined by Callon (1999) is in the ability of the competence group as a whole to encourage others to accept the knowledge created through this kind of process. Therefore, co-produced knowledge, if accepted by external parties (such as river managers), is presented and backed by the group as a whole and those accepting the knowledge are also accepting responsibility for it. Questions of accountability have been raised within research of this nature (Carr *et al.*, 2012), however, if the process is open and transparent, with clear goals and roles from the outset, then accountability should be understood and accepted by all

participants. If accountability of co-produced knowledge is not accepted by participants, then it should not be used as a tool for change.

This chapter has outlined the deliberation process which led to the final results produced by the overall participatory study, and the implications of the Ebchester Study findings have been discussed within the context of relevant academic literature as well as the knowledge provided by the group. The next chapter will discuss the wider findings of both the Ebchester Study and the Organisational Review and their implications for participatory practice in river research and management.

Part IV:

Study synthesis

Chapter Nine

The role of participation and knowledge co-production in river management

9.1 Introduction

In Chapter Two, the main bodies of literature surrounding co-production of knowledge and participation for river management were discussed. It was demonstrated that there exists a wealth of literature on these topics, which can be roughly separated into theoretical statements of the necessity of high-level public engagement, and the more practical group of case studies around attempts at participation in river management. However, after discussing these literatures, it was identified that some questions and issues remain, which are yet to be fully addressed. These include:

- i) An approach in which 'creation of knowledge comes first, then application of the knowledge to a problem' persists in many river management contexts;
- ii) There is a lack of critical review of the participatory process and a lack of focus on expert learning;
- iii) There are problems associated with achieving high-level involvement (e.g. co-production) at a range of scales and in a number of locations.

By exploring the problems that exist (informed by the research of this study), we can begin to address the gaps outlined in i and ii above, and to develop an understanding of the role of different forms of participation and what is most appropriate in certain contexts. Therefore, this

chapter will draw on analysis of both the Organisational Review and the Ebchester Study, with an aim to draw out wider lessons about the participatory process. The chapter will address the above points by first, providing a critical review of the participatory process used in the fieldwork for this thesis (the Ebchester Study), and also highlighted through the Organisational Review, in which the limitations of participation in real situations will be outlined, and aspects of the process which can act as limiting factors, will be discussed. This section will also aim to determine the reasons for the persistence of Public Debate (Callon, 1999) and Mode 1 (Gibbons *et al.*, 1994) approaches, based on the critical review. Secondly, specific focus will be placed on one of the primary issues identified through this study: participant apathy, and what this means for participatory processes and theory. Thirdly, the potential benefits of participation, as identified through the present research will be outlined, and the potential uses of participation for river management will be discussed. Fourthly, the case study of modelling as an approach to participatory practice in river management will be presented, and finally, the overarching questions of optimum participation levels, and whether co-production is a reasonable expectation, will be considered. The next section considers the participatory processes used and analysed in this study and offers a critical review in the context of current knowledge production theory.

9.2 Critical review of the participatory process and the notion of knowledge co-production

As highlighted in Chapter Two, there are numerous peer reviewed sources which suggest that participatory approaches and the co-production of knowledge are what river managers should now be aiming for. However, while there are many studies claiming the success of participatory approaches that are opened up to the wider public (e.g. House, 1999; Junker *et al.*, 2007; Antunes *et al.*, 2009), higher level engagement which leads to the co-production of knowledge (Callon, 1999) or follows the Mode 2 style of knowledge production (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001, see Section 2.3 for discussion) is still uncommon. This section will first consider the participatory approaches involved in this investigation (from both the broad scale study and the local Ebchester study), within the context of a number of knowledge production concepts (e.g. those of Callon, 1999, Gibbons *et al.*, 1994 and Nowotny *et al.*, 2001, critiqued in Section 2.3). It will then address some of the issues identified within these studies which may help to explain the reasons for the continuation of lower levels of engagement, and the difficulty in achieving true co-production in river management.

9.2.1 Forms of participation identified in river management projects

Within and between projects, level of engagement may vary and different approaches may be used for different aspects of a study, as has been demonstrated by almost every project considered within this study. Table 9.1 summarises all of the approaches to participation that have been employed either by members interviewed as part of the Organisational Review, or the Ebchester Study, and it aims to demonstrate the level of engagement used for various purposes.

Study member, project aim and overall approach	Types of participation used	Levels of participation utilised (based on Arnstein's classification, see Table 2.3 for definitions)	Overall mode of knowledge production
<p>P1 Floodwater storage. Consultants made decisions, then agreed with SHs via moderators. Limited and late public involvement</p>	<ul style="list-style-type: none"> -Roundtable talks and workshops with experts and SHs -Limited public consultation 	<p><i>Consultation and informing</i>, for public, <i>Placation</i> for SHs</p>	<ul style="list-style-type: none"> -PDM (with elements of PEM) -Mode 1: academic context, homogeneity, traditional QC -Mode 2: transdisciplinary, social accountability
<p>P2 Flood water storage. Consulted with public over design elements, and considered local concerns during implementation</p>	<ul style="list-style-type: none"> -Meetings with local authorities to present/discuss plans -Public meetings/exhibitions/Q&A -Project house -Web page -Workshops with technical experts -4 month public consultation 	<p>Primarily <i>placation</i> as public has no final influence, but partial <i>partnership</i>, as some negotiation is admissible</p>	<ul style="list-style-type: none"> -PDM -Mode 1: academic context, homogeneity -Mode 2: transdisciplinary, social accountability, traditional and novel QC
<p>P3 Develop solution to flooding problem and WFD requirements, subsequent consultation with public</p>	<ul style="list-style-type: none"> -RBMP public enquiry -Public consultation of plans -Press conference -Publication in Bulletin of Acts, Orders and Decrees -TV advert -Web page -Information market -Site visit and debates 	<p>Widespread <i>consultation</i> and <i>informing</i> for public, some degree of <i>placation</i> for SHs</p>	<ul style="list-style-type: none"> -PEM primarily, PDM where required by WFD -Mode 1: Academic context, homogeneity, traditional QC -Mode 2: transdisciplinary, social accountability
<p>P4 Restoration of river corridor. Involve public in design to give them a say and partly to reduce conflict</p>	<ul style="list-style-type: none"> -Meetings for presentation of plans -Public voting on design -‘Local parliament’ elected for implementation of design plans 	<p>Limited to <i>informing</i> the public for technical aspects, but for design aspects, they employed <i>delegated power</i> to the public</p>	<ul style="list-style-type: none"> -Primarily PDM, with some PEM -Mode 1: Academic context -Mode 2: transdisciplinary,

9. Role of participation and knowledge co-production in river management

	<ul style="list-style-type: none"> -Party to publicise work -Questionnaires -Site visits for experts and government officials -School archaeology project 		heterogeneity, social accountability, traditional and novel QC
P5 Project instigated by farmers, farmers given control over design but not technical aspects	<ul style="list-style-type: none"> -Workshops with all affected plus experts; -Roundtable with SHs -One to one with two elected lead farmers -Information provision meetings for all -Newsletters -Home visits to those affected 	<i>Delegated power</i> for the public in aspects of project buy-in and design. <i>Consultation</i> ranging through to <i>partnership</i> for affected families in technical aspects	-CKM/PDM -Mode 2
P6 Water quality, biodiversity. Decision-making internal to organisation, rigid structure for communication of plans to public. At times, work conducted before consultation.	<ul style="list-style-type: none"> -Drop-in sessions for information provision to local people -Site visits for SHs -Evening presentations for interested groups 	Primarily <i>informing</i> and <i>non-participation</i> for wider public, some <i>participation</i> for land tenants and farmers, with a limited amount of <i>partnership</i> on small-holdings (i.e. land closest to farm buildings)	-Primarily PEM, some PDM close to farms -Mode 1: academic context, homogeneity, autonomy, traditional QC -Mode 2: transdisciplinary
P7 Reduced flood risk. Topic was decided internally, subsequent decisions were made between experts and SHs (landowners and farmers, who were invited to suggest actions/locations)	<ul style="list-style-type: none"> -Information stands at shows -Information event for SHs -Workshops for all affected -Steering groups with local experts and landowners/farmers -Hydrological model demonstration -Personal visits to farmers -Educational activities with schools/public 	Ranges from <i>informing</i> to <i>partnership</i> for public, with some <i>delegated power</i> to those most affected (landowners, farmers), particularly concerning what actions may take place where	-PDM, with some elements of CKM -Mode 2
P8 River rehabilitation, fisheries, flooding, other. Put	<ul style="list-style-type: none"> -SH analysis -Analysis of constituents 	Some degree of <i>citizens control</i> , depending on nature of project (aim of P8 is often to encourage volunteers to	-Primarily CKM (projects often developed in response

participation at centre, to shape project. Often use groups who have a unifying cause	-Participants as volunteers to provide information and work in catchment -Varies depending upon nature of work	take over projects as their own). Also utilise <i>delegated power</i> , as well as all other stages, stopping at <i>non-participation</i>	to public interest/need) -Mode 2
P9 River restoration, fish passage, assistance to local action groups, education. Basic design work internal, then opened to public comment and suggestion. Use local knowledge of environment in design. Level of involvement depends on level of community value of a project. Engagement through delivery.	-Presentations to public -Roundtable discussions with public/SHs (vary depending on level of understanding in room)	Focus on <i>delegated power</i> , with some <i>partnership, placation and consultation</i>	-PDM and CKM -Mode 2
P10 (Ebchester project) Aim to utilise public knowledge to address a situation of concern <i>to the group</i> . Group as a whole has full control over topic of research and all involved in interpretation of results.	-Drop-in to establish points of concern in catchment -Roundtable discussions with those interested in participating -Site visits for further sharing of knowledge -Roundtable to discuss value of model results and develop model	<i>Citizens power</i> in that the members of the CG are able to set research agenda, although the data collection and modelling aspects mean that public did not fully take on the task themselves. <i>Delegated power</i> to the group in that they provided the knowledge that shaped the project. May be as low as <i>placation</i> level for communication of model results	-CKM -Mode 1: disciplinary -Mode 2: context of application, heterogeneity, reflexivity/social accountability, traditional and novel QC

Table 9.1 Forms of participation and knowledge production used in the examples within this study. Notes: SHs = stakeholders; QC = quality control; PEM = Public Education Model; PDM = Public Debate Model; CKM = Co-production of Knowledge Model. See Table 2.1 for the five categories used to distinguish between Mode 1 and Mode 2. *Homogeneity* of experiences, in this case, is considered to be the extension of knowledge production to groups not directly associated with the managing organisation, rather than the extension from academic research to consultants, managers, governments etc., as implied by Gibbons *et al.* (1994). ‘Overall mode of knowledge production’ is based on classifications by Callon (1999) and Gibbons *et al.* (1994)/ Nowotny *et al.* (2001)

Table 9.1 allows the identification of a number of the issues associated with trying to ‘classify’ approaches to participation and types of knowledge production. These include: i) a range of levels of participation are often used within one project; ii) different levels of participation being appropriate for different groups; iii) employment of the same participatory approaches resulting in different levels of outcome, and iv) the use of multiple characteristics to define each form of knowledge production makes assignment difficult as processes are often a hybrid of a number of the characteristics at varying levels (this refers primarily to the five distinct points used to categorise Mode1/Mode2 knowledge production, although both the authors proposing Mode2 (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001), and Callon (1999), who proposes the CKM model, suggest that the higher level participation that results in co-produced knowledge can operate in tandem with lower level participation such as Mode 1 and PDM). Each of these issues is explored in turn, below.

9.2.1.1 Use of a range of participation levels

It was noted by a number of the interviewees for the broad scale study that participatory approaches varied according to a number of factors, which included the required outcome, type or number of people involved and resources available. In many cases, the large number of people affected by a project meant that a tiered approach to participation was adopted, in which those with the biggest stake and/or the most relevant (and qualified) expertise would be offered the greatest levels of involvement, and sometimes have a degree of control in the decision-making process. Level of involvement and control would decrease as the participants became less ‘qualified’ to comment on a matter, or less affected by a process. Therefore, it would be inaccurate to suggest that any of these projects were categorically positioned within one of the models/modes of knowledge production or levels of participation.

9.2.1.2 Employment of the same participatory approaches can lead to different outcomes

Although many of the groups considered that they used participatory approaches from a standardised range, the outcomes of these approaches were vastly varied between the groups. For instance, workshops and meetings open to all those affected by a project were cited as a form of participatory process by eight of the ten projects. However, within those projects that used workshops, the actual levels of participation (for those affected by a project, but not necessarily ‘qualified’ to comment, according to each interviewee) included virtually all of Arnstein’s (1969) range, from non-participation, through to delegated power. Notably, P8 and P10 (see Table 9.1), the only projects to attempt Arnstein’s citizen’s power, did not refer specifically to the use of ‘workshops’. P8 and P9 hold meetings, as do many of the other groups, but (partially) through these meetings, P8 and P9 achieve levels of engagement so high that in some cases they are able

to 'hand over' their projects to the citizens involved and provide them with the opportunity to adopt the project as their own. It is evident, therefore, that factors other than classification of participatory approach determine the level of engagement offered within a project. Factors such as the motivations, goals and priorities of those instigating the research, as well as scale of a project and available resources, influence the level to which a certain approach (e.g. a workshop) can (and should) engage and involve interested parties. The limitations that have been proposed concerning Arnstein's hierarchical approach are evident here, particularly the assumption that participatory outcomes automatically improve with increasing degrees of involvement (see Clark, 2002 and Collins and Ison, 2009). It is more the case that appropriate level of participation will vary depending upon context and objectives (e.g. Rowe and Frewer, 2000; Richards *et al.*, 2004; Kindon *et al.*, 2007; Tippett *et al.*, 2007; Reed, 2008). Clark (2002) recommends that Treby's (1999) approach to participation classification (Figure 2.2) is more appropriate for river management because it is not hierarchical, instead it assumes that each sector has the same status and that the method of participation is chosen based on the nature and context of decisions to be made and of ultimate goals. It allows the type of participation to be chosen based on a set of aspirations and will vary between places and between times (Clark, 2002). Following Treby's (1999) system of classification, it is acceptable for the different projects addressed in this study to select participatory processes appropriate to the goals and aspirations of a specific part of a project. For example, 'delegation' according to Treby, can be a formal process with a two-way flow of information, but little consultee influence on decisions, or it can allow consultees' feedback to feed directly into joint decisions. Furthermore, Treby reserves the term 'participation' solely for a process in which consultees are able to inform decisions through a two-way process. This distinction serves to prevent the use of the term 'participation' to suggest that non-experts have been involved in a process to a higher degree than is accurate.

Some authors have developed Treby's notion further and aimed to classify participation according to the *nature* rather than the *degree* of participation (e.g. Rowe and Frewer, 2000), with emphasis on how effective a method is at achieving a certain goal (Reed, 2008). This approach would be particularly appropriate for river management, where projects are often on a large scale (e.g. catchment scale) and the project and participants benefit from varying degrees of involvement (such as allaying concerns of the general public, to incorporating the input of local residents who have extensive experiential knowledge). In this way, a more efficient approach could be taken to participation, and this is demonstrated, albeit in an informal manner, by many of the larger projects involved in the broad scale study (although, it is evident that the motives and rationale must still be right, in order for the process to be successful). Collins and Ison (2009) note that

participation should be seen not as a 'bracketing of power', but rather as 'a process of social learning about the nature of the issue itself'. Like Treby, what is of importance to Collins and Ison is the overall outcome of the process, rather than individual participatory methods and that a fixation on hierarchical approaches to participation restricts the policies and practices that attempt to encourage participation.

The way in which a certain participatory procedure is carried out (and the motivations for conducting the procedure) will also influence the level of knowledge production that is achieved. For example, workshops may be conducted in which research methods are demonstrated to interested parties, but the response and comments from the participants may not be fed back in to the research process (e.g. with hydrological or hydraulic modelling). In this case, PDM or Mode 1 knowledge production dominate. By making a small adjustment to the process, in which comments and opinions on the model outputs are used to inform and develop a model, CKM or Mode 2 (and their claimed merits, see Section 2.3) may be achievable.

9.2.1.3 Difficulty in assigning one mode of knowledge production

While incorporating the feedback of a user group on model performance into the process can help to create knowledge together within that group, that process alone may not achieve true co-production of knowledge (as defined by Callon, 1999), because the group does not necessarily have some joint cause or motive to have driven them into action. Similarly, the research approach may respect and incorporate a heterogeneous range of experiences and knowledge within the modelling process and be reflexive, with novel modes of quality control. However, if it fails to consider a number of disciplines (for example, hydraulic modelling is highly focused on a small range of physical equations), then it may not be considered as purely Mode2 knowledge production. Callon (1999) does note that his three models are not exclusive to each other and that one may complement another, such as PDM existing for the 'general public', while CKM takes place within a more focused group of appropriate members, with an appropriate range of knowledges. Similarly, Gibbons *et al.* (1994, 14) suggest that Mode 2 knowledge production supplements, rather than supplants Mode 1. It is essential that the two levels are able to run concurrently. Not all decision-making processes within river management are accompanied by a controversy and/or a group moved to the point of action (one of the fundamental aspects of CKM), and in many cases, particularly for river management organisations, the remit of the project is fixed (e.g. flood risk management), the only flexibility available to them may be the way in which the topic is researched for decision-making and they must use the resources available to them within a defined space, time and resource limit. Furthermore, according to the classification requirements presented by Gibbons *et al.* (1994, see Table 2.1), all of the above projects would be

considered heterogeneous for the simple fact that they are conducted outside of the research institution. However, heterogeneity may be the only factor by which a project would be considered as Mode 2. In this event, should a project be considered as Mode 2, simply because it is carried out by a non-research organisation? Godin (1998) argues that all knowledge production is heterogeneous to a degree and that rather than having two modes of knowledge production, one mode exists, in which most of the characteristics of 'Mode 2' are held, but which has a varying extent of heterogeneity over time. Godin (1998) notes that some of the other characteristics used to define Mode 2 (context of application and transdisciplinarity) are also not exclusive to Mode 2, which may explain the difficulty in applying either Mode 1 or Mode 2 to empirical, actual projects. The two simply cannot be distinguished for a number of real-world scenarios.

9.2.2 The role of governing factors in participation and knowledge production

The above issues can be associated with a number of governing factors, including scale, power relations, motivations, resources, trust and perceptions (e.g. of the validity of 'non-expert' knowledge). It is the role of these governing factors which may explain why, although difficult to assign a model/mode to a certain project, many of the features of Callon's PDM and Gibbons *et al.*'s Mode 1 knowledge production models continue to dominate river management practice. The influence of the dominant factors is discussed below.

9.2.2.1 Is there an optimum scale for involvement?

The influence of project scale on the participatory process used, and on the type of knowledge production achieved are discussed partially in Chapter Four (Section 4.3.2) and in Maynard (2013). It was established that scale was one of the major controlling factors on the type/level of participation used by river management organisations, and that as project scale increases, the complexities and logistical obstacles to participation increase (echoed by a number of authors, including Adams and Perrow, 1999; Hughes *et al.*, 2001; Adams *et al.*, 2004), thus deeming higher levels of knowledge production more difficult to achieve, and indeed, apply. However, this relationship may experience further complications if scale is too *small*. When a research project is instigated by an individual (as in the Ebchester Weir Research Group), the level and range of certified expertise may be limited. For example, the only 'certified' expert in the Ebchester Weir Research Group (EWRG) was the instigating academic. This results in a less diverse range of research expertise (in this case limited to flow and sediment dynamics, which do not cover all of the processes occurring in the river environment, which include water quality issues, ecosystem dynamics, biological requirements, engineering aspects of weir impact and design). While the theory behind Callon's CKM suggests that the diversity of these issues may be covered by the

group as a whole and that a new knowledge will be developed within the group, there remains a certain stigma within the research community around the value of 'experiential knowledge' (discussed in Section 9.2.2.2) and the very nature of group formation (that it occurs through a situation of concern to a group of people) may mean that certain areas of knowledge or experience are under-represented. This scenario is reflective of the commentary provided by Godin (1998), which states that knowledge production has always been homogenous and disciplinary, with varying levels of extension to other types and topics of knowledge.

Spatial scale is often overlooked in planning for resource management and switching between large and small spatial scales in management approaches carries a number of complications (Fox, 1992; O'Neill, 2005). House (1999) notes that effective participatory processes usually operate at the small (reach) scale, and it is evident from Table 9.1 and the results presented in Chapter Four that the management approaches employed for smaller scale projects, and particularly the participatory aspect of those approaches, are difficult to employ successfully at larger (e.g. catchment) scales. Newson and Large (2006) also comment on the disparity between management or research projects at different scales. They note that the 'pristine' and 'upland' foci of academic research are not concurrent with the pragmatism that is necessary when aiming to achieve national scale river rehabilitation. Such contrasts mean that there may be difficulty in aligning academic and organisational river knowledge, as well as local and experiential knowledge.

O'Neill (2005) discusses some of the difficulties associated with applying water management methods that have been developed in small rural watersheds (and often by voluntary partnerships, as the present study shows, these two characteristics are often related), to larger, urban watersheds. It is established that the differences between political, social and physical characteristics of watersheds of varying sizes make collaborative work at the catchment scale unsuitable (as suggested by Chess and Gibson, 2001), and Eden (1996) notes that policy must be developed for large-scale, high-risk impacts, making participation for those implementing policy very complicated. As with the present study, O'Neill (2005) found that factors which have been identified as necessary for effective watershed management are dependent upon organisational responses, perceptions and experiences, all of which are unevenly distributed across small (or rural) and large (or urban) watersheds. The relationship between organisational motivations for participatory approaches and success is discussed in Chapter Four (Section 4.3.3) and it is demonstrated that if participation is carried out under duress then the outcomes can be superficial and the process unsuccessful. Furthermore, the differences which exist between

conceived, perceived and *lived* spaces (Lefebvre, 1991) can exist on different scales (e.g. lived and perceived understandings may be much more localised than conceived understandings) and may make a joint understanding of a large scale watershed difficult. When large scale projects are carried out under the supervision of statutory or governmental organisations, unifying the perspective of the managers/consultants (conceived space), and those of the local experts and people affected by management decisions (lived space), can become very difficult as ideas, goals and priorities deviate. This was particularly evident for P3, in which public opinion and knowledge was omitted entirely from the decision-making process and resulted in stagnation of the project.

Scale is important both within and between projects. While the Organisational Review demonstrated that difference in scale between projects can affect the approach to participation and the overall scope of a project, the Ebchester Study has shown that scale can also play a role within a project. For example, some of the EWRG members were concerned primarily with the immediate spatial implications of channel modification (e.g. flooding or water level changes within tens of metres of the weir). Other members however, who had experienced the river on a range of scales, were more concerned with the broader spatial implications of weir repair. For example, M6 (the angler), was aware of and concerned with downstream implications of vegetation changes and water levels, as a result of their experience in a range of locations along the reach of the river, but also detailed knowledge of each of the sites they frequented. Knowledge also differed according to scale in terms of the magnitude of impact of a certain feature. This was evident through the knowledge possessed by every group member about the impact of Derwent Reservoir, but the limitation of the knowledge of small scale impacts to the area local to the weir. These observations are, again, demonstrative of the lived, perceived and conceived scales of the river (as discussed by Lefebvre, 1991) and the value of knowledge at different scales should be considered at the outset of a participatory process to encourage integrated discussion of all scales, between all group members.

Associated with these complications of process or system understanding are the difficulties of the recruitment of appropriate participants and fair representation at watershed scales (O'Neill, 2005). In 'physically diverse' watersheds, different types of knowledge between areas exist and the perceptions of non-residents may result in the divergence of diagnoses 'about the nature and solution of water problems' (O'Neill, 2005). Many of the interviewees for the large scale projects commented that participation was limited to avoid conflicting agendas and resistance, while all of the smaller scale projects used the knowledge of those with experience and those affected, to define the issues. As well as variations in types of knowledge, across different spatial scales,

water managers are likely to encounter contrasts in the goals of different groups (e.g. governments may wish to improve the welfare of a region, while local participants seek to survive as a community), which can cause problems when trying to find common ground between groups of actors (Fox, 1992). This is considered to be one of the primary driving factors in the level of participation used by each group. The organisations (when referring specifically to the Organisations involved in the Organisational Review, they are termed 'ORO's') with large scale projects, in many cases, were responsible for tasks related to human and environmental welfare, such as flood risk management (e.g. P1, P2, P4). The priority of the project managers was to reduce flood risk, while many reported that participants were concerned only about local implications of engineering and restoration works. This is linked to the discussion by O'Neill (2005) that those in the lived space only envisage and contemplate the area that they can see or experience in their day to day lives, while consultants and managers are responsible for managing resources and processes on a catchment scale.

There has been some discussion of the problems associated with switching between scales (e.g. Fox, 1992; Fisher, 1994; Newson and Newson, 2000; Newson and Large, 2006). Fox draws on hierarchy theory (originating in the discipline of ecology and discussed by O'Neill *et al.*, 1986; O'Neill, 1988) for a number of principles which can be applied to community resource management and the issue of switching between scales. Briefly, hierarchy theory suggests that i) rather than having a 'fundamental level of analysis', data collection and structuring methods must be considered within the context of the specific issue in order to choose the correct level of hierarchy (or spatial scale) at which to study a problem, ii) it is possible to predict the influence of a process or action at a higher hierarchical level (or greater spatial scale) on lower levels, but this notion cannot be reversed – at the larger scale, impacts are often greater than (or different to) the sum of the parts. Therefore, Fox (1992) suggests it cannot be assumed that collating information from a number of small scale studies will provide an accurate representation of processes on the larger scale. Similarly, Newson and Large (2006) describe the uncertainties in knowledge encountered when switching scale, often as a result of the variation in the mode of information compilation at different scales (in geomorphological studies). Additionally, Stone (1972), described the attempt of geographers to deal with representation of environmental processes at a range of scales, and concluded that large scale field study and data collection cannot be translated into small scale conclusions and analysis. In summary, both scaling up and scaling down are problematic. This causes a problem for the river management field and raises questions about the frequent suggestion that river management processes be participatory and create new knowledge. O'Neill's study concludes that scaling up management approaches can

lead to difficulty in complying with guiding principles and practitioners may struggle to involve those most affected by management decisions, an achievement of which is one of the fundamental premises of community resource management (Fox, 1992). If, as O'Neill (2005) suggests, communication with all those affected by decision-making cannot be conducted at the large scale, and the compilation of a number of system understandings cannot be relied upon for an accurate representation of the large scale (as offered by Fox, 1992), then another approach to catchment scale management with high-level participation and involved knowledge production, must be sought.

Consequently, the feasibility of high-level participatory approaches and the notion of knowledge co-production for large scale organisations, must be considered. Alexander *et al.* (2010) suggest that as a result of the inherently local nature of water issues, 'indicator methodologies', designed to identify and rank issues to be addressed, should be used in management practice. When combined with deliberative engagement processes, the approach can lead to collective learning and collective action. However, they suggest that in practice, their approach is still most effective for local water managers. Using small scale fisheries information as a case study, Moreno-Báez *et al.* (2010) demonstrate an approach which may work towards dealing with these issues of scale. By collating local knowledge from many participants over a large area through a rapid appraisal process, and compiling the information within a GIS system, participatory maps were created and used as a tool for a secondary round of validation, in which selected local experts verified the information provided over the large scale. The selection process of local experts involved criteria such as a minimum number of years fishing experience and community residency, as well as selecting some participants who had been involved in the initial rapid appraisal, and some which had not. It was found that the interaction of the participants with each other, and with the large scale data, helped to increase the precision and accuracy of the data, although it is noted that the process is not designed to replace either scientific research or in-depth investigations at specific sites. This method appears to achieve the goal of incorporating numerous small 'pockets' of knowledge to a larger scale understanding, but does not directly address the issue outlined by Fox (1992), that the sum of all the small scale data do not accurately represent processes on a catchment scale. However, it is at this point that the role of the traditional scientific experts is imperative (the importance of these actors is maintained in CKM and in Mode 2). Traditional experts generally have an understanding of the processes at play across an entire system. This knowledge, combined with many local portraits of processes and features within a system can help to develop an understanding of the details of a catchment and of the expected impacts of changes to a process or feature (as has been documented by Jinapala *et al.*, 1996). Additionally,

tools such as numerical models may be utilised in these situations to predict catchment responses based on a compilation of local features. In the Ebchester case study (and to varying degrees in P7, P8 and P9, see Table 9.1), the participants of a group were given the opportunity to comment on the validity of data already collected (both traditional scientific data and on data collected within competence group meetings) and to reflect upon the results those data produced once they were placed in the catchment scale context. Changes to the research focus, or the model application were made according to this second round of review. In the very small scale projects (most notably the Ebchester Study), the small number of participants meant that no new members were available to review preliminary data sets, which could lead to a negative feedback effect, in which the original data provided is not questioned fully. However, if this approach was to be applied specifically in order to allow the extension of high-level participatory and knowledge production processes to large scale projects, then the absence of 'data reviewers' is unlikely to be a significant issue.

9.2.2.2 Validity and acceptability of experiential knowledge

Another aspect which can hinder the uptake of participatory processes and therefore the co-production of knowledge is the lack of trust or respect in experiential knowledge, and the absence of mechanisms to 'validate' experiential or jointly produced knowledge, on the part of the river managers, academics or funding bodies. Lack of 'scientific robustness' was considered to be an obstacle to participatory working for many of the larger OROs involved in this study, as well as for interdisciplinary researchers (see Section 2.5.1 and Appendix B). Regardless of whether research is accountable for its levels of socially oriented quality control, very often the outputs are still ultimately judged according to their level of scientific rigour (Godin, 1998). A number of approaches have been proposed which are intended to 'validate' the knowledge provided by the public (through expert review), and have been found to increase confidence in the data (e.g. Dickinson *et al.*, 2010; Bonter and Cooper, 2012). However, by assuming data and knowledge need to be validated and by electing certified experts to do this, practitioners may reinforce the hierarchical divides that theories such as those offered by Callon (1999), Gibbons *et al.* (1994) and Nowotny *et al.* (2001) seek to dissolve. CKM and Mode 2 forms of knowledge production function through the creation of a *new* knowledge, which accounts for a new product based on input from all participants, thus making the components much harder to quantify or validate. Indeed, the very goal of the project is not to label and grade knowledge types, but to create a new knowledge, the trust of which is developed through the process of its creation, in which existing knowledge and assumptions are contextualised by the group situation and reformulated. 'Expertise' therefore, should not be defined through attributes and formal qualification, but should be

considered as a process, and only toward the end of the process, can participants (including scientists), be considered to have relevant expertise of a given issue (Limoges, 1993). Eshuis and Stuiver (2005) demonstrated the importance of this when conflict between two types of knowledge threatened to divide a research group working on a nutrient management project in The Netherlands. However, the ultimate realisation that different sources of knowledge could be valued in different circumstances allowed the whole group to view the knowledge types as complementary and the local knowledge was considered to be equally as valuable and viable as the scientific knowledge, thus resulting in a new way of learning for all involved.

While local knowledge cannot always be quantitatively validated (and may not always need to be, as discussed below), the very process of participation can validate the wider research process. By involving participants with local experience, questions can be formulated which are appropriate and meaningful (Kindon and Latham, 2002) and may enable those who are affected by decisions and those who have to address the questions, to be able to deal with complex issues (Flowerdew and Martin, 2005, 164). Other aspects of a participatory process which assist in the validation of the wider project include the high level of detail used to record information transfer and development. This level of detail can provide a 'full and open audit' of how and why ideas are formed (Flowerdew and Martin, 2005, 165). A narrative between the perspectives of participants and researchers is also provided, which shows reflexive objectivity in the process, and the building of trust between groups allows for the sharing of deeper insights (Flowerdew and Martin, 2005, 165).

Rather than experiential knowledge being inferior (or 'deficient' as termed by Sturgis and Allum, 2004), it is an understanding which is framed differently and therefore its quality cannot be measured against traditional scientific standards. In many cases, there are similarities between the nature, content and mode of acquisition of the knowledge possessed by 'certified' and 'non-certified' experts, the issue lies with how 'experts' classify the types of knowledge, based on its source (Lane *et al.*, 2011). Ziman (2000, 206) notes that in the development of knowledge, as theorised in Mode 2 and post-academic science, the epistemic status of that knowledge is 'entirely pragmatic', and therefore is not intended to be judged according to academic standards, which are very often different to the required practical outcomes. A project in which knowledge has been validated by a diverse group can serve to extend the benefits of the decisions made beyond scientific and technical components. Social benefits include a management approach which addresses the needs and interests of all involved, thus leading to wider acceptance of the process as a whole. This was experienced by a number of the projects involved in the current

study (Projects 5,7,8,9 and 10, see Table 9.1), as well in other published case studies (e.g. Ritzema *et al.* 2010; Teixeira *et al.*, 2013).

In many cases, and certainly in the contexts described by Callon, the involvement of affected members of the public in a research process is instigated by some shortfall in the traditional approach to scientific decision-making or management. Therefore, the very fact that their insight is required suggests that there is no equivalent supporting knowledge with which to validate their assumptions. Therefore, as an alternative to focusing on the validation of experiential knowledge, participatory and knowledge production work should perhaps be carried out to increase public trust and to gain a context specific insight to a process or a model's performance. This type of motive was evident for projects 5, 7, 8, 9, and 10, all of which had greater levels of success in utilising experiential knowledge, than the other projects in this study. This outcome has been documented elsewhere, for example, Oliver *et al.* (2012) found that farmers' knowledge is essential in validation of the predictions of decision support systems. It helped to develop a more integrated and collaborative approach, and ultimately, the refinement of science by the local experts (Raymond *et al.*, 2010; Edwards and Smith, 2011). It has been suggested that local knowledge can be more reliable than spatial knowledge (McKall and Dunn, 2012) because it 'embodies generations of practical knowledge and...operates in holistic systems' (McKall and Minang, 2005, 343). Participants are not involved in a process solely to provide information, but also to develop and verify process assumptions and initial results or interpretations, thus leading to a more credible account of a process or issue (Flowerdew and Martin, 2005, 165). Project 7 in particular, used the knowledge of local landowners and farmers to evaluate the impact of certain location choices for catchment management applications. Again, in the Ebchester Weir project, the group members were able to highlight the inability of the preliminary model set up to predict appropriate flow levels following weir restoration. Ritzema *et al.* (2010) noted that their incorporation of farmers' local knowledge and scientific knowledge allowed them to apply simulation models to a case which could not be investigated in the absence of long-term observation data, and achieved satisfactory results in model validation and establishment of the context-specific management needs. Furthermore, the dynamic and context specific nature of local knowledge (Teixeira *et al.*, 2013) means that it can be more responsive in certain cases than assumed, general, process knowledge, and can lead to a more reflexive and wider-reaching (Teixeira *et al.*, 2013) approach to knowledge creation and decision-making strategies.

Ritzema *et al.* (2010) propose that a situation in which the assumptions of models and the value of participant input are acknowledged leads to more productive environmental planning than a

situation in which model inputs are exactly understood, but participants feel no value of their contribution. Indeed, model uncertainties may be *reduced* through the incorporation of local knowledge. Based on the assumption that validation of local knowledge should be for the benefit of those affected by decision-making, as well as river managers/researchers, and that qualitative methods can be as valuable as quantitative methods in the right context, then it could be concluded that the best way to validate knowledge is to present it to others who are appropriately qualified through their experience of the issue, system or environment (such as other members of the public with local experiential knowledge, and to the wider community). This approach has been trialled and approved by a number of authors in recent years, including Hare *et al.* (2003), Ritzema *et al.* (2010), Lane *et al.* (2011) and Oliver *et al.* (2012).

Therefore, perhaps, projects should not be assessed based on questions of how high a level of participation they can achieve, or which of the models/modes of knowledge production they lead to, but more on the outcomes of the research, in whatever form it takes, and whether it meets the needs of those affected or involved, and whether such outcomes have offered sufficient opportunity for those affected to participate, should they wish. This statement does not require that local, lay non-expert knowledge (however it is classified) be disregarded, but that it be employed in the most relevant situations, and not enforced blindly in response to the growing trend. As Godin (1998) suggests, 'to define is to make a claim against other possible understandings'. Ultimately, there may not be a quantitative solution to the issue of local knowledge validation, but perhaps this form of validation is not necessary (as argued above). The focus of this issue should then be on how experiential or local knowledge (and therefore co-produced knowledge) is perceived and marketed. If the qualitative and over-arching strengths of participatory processes and co-produced knowledge are re-framed and effectively portrayed to those demanding them (e.g. funding bodies, some academics, river management organisations), a new understanding and a new level of trust may be achieved. The scale-related practicalities and the acceptance of experiential knowledge in a participatory process are not the only limiting features. Even at the small scale, and when experiential knowledge is valued, there may be unexpected hindrances to the process. The most significant of these for the Ebchester Study, the loss of participants during the process, is discussed below.

9.3 Unexpected challenges within the study

As mentioned in Chapter Eight, a significant portion of the group members decided not to be involved with the Ebchester Weir project following the restoration of the weir. This raised a number of questions and thoughts about the involvement of participants, including:

- Motives for participation
- Impacts of losing members during the participatory process
- Assumptions that all members have a desire to be actively involved in decision-making processes
- The importance of a controversy situation in uniting group members

To address these issues and to enable further understanding of the participatory process as a whole, the remaining members of the group were asked to reflect on their experience. The information gathered in response to this inquiry is used as the basis of this discussion, and some response (and absence of responses) from the members who left the group, are also included. The following sections discuss the assumption that people wish to be involved, reasons for loss of interest, and the implications this has for the process.

9.3.1 Does everybody wish to participate?

Within published literature, the supposed benefits of a high-level participatory approach to environmental and water management are abundant and include attributes such as social learning (Henriksen *et al.*, 2009), empowerment (Petts, 2007), identification of community needs (McDonald *et al.*, 2004), increased project support (Carr *et al.*, 2012) and robust research results (Reed, 2008), to name a few (see Section 2.4.4 and Appendix A). In addition to this, there is a body of theoretical literature which describes the benefits of knowledge which is co-produced between a diverse group of relevant actors (Funtowicz and Ravetz, 1993; Gibbons *et al.*, 1994; Callon, 1999; Nowotny *et al.*, 2001) usually around some topic of contention (e.g. Latour's 'matters of concern' (2003) or Callon's 'hot situations' (1998), see Section 2.3.7). Many authors describe the right of citizens to be involved in processes of decision-making which affect them (e.g. Renn *et al.*, 1995; Pahl-Wostl *et al.*, 2007) while Jasanoff (2004a) and Wynne (1992c; 2007) suggest participation should be viewed as a democratic right. This is echoed in current environmental legislation (e.g. WFD and Aarhus Convention). However, as well meaning as these scripts are, a common theme within both the practical and the theoretical literature is the underlying assumption that those who have the right to be involved, also have a *desire* to be involved. Moreover, there is a growing assumption that 'any type of research other than academic research' is preferable, that any source of knowledge is as reliable as another and that

knowledge should always be co-produced (Godin, 1998). Mirowski and Sent (2008, 670) suggest that theories of knowledge production such as Mode1/Mode2 and the Triple Helix are based upon the presumption that marketised science in any form will serve to 'enhance freedom, expand choice, encourage participation and improve welfare'.

These assumptions can cause problems when they lead to the instigation of research processes that assume there will be a plentiful supply of willing volunteers to contribute time, effort, knowledge and expertise. In the Ebchester Weir project, 11 individuals expressed interest in the issue and attended the first official Competence Group (CG) meeting. However, (as described in Section 8.2.1), by the fourth CG meeting (and following the restoration of the weir, the main goal for many of the group members), numbers were reduced dramatically to three. The reasons for the loss of participants are discussed below.

9.3.2 Reasons for participant apathy

A number of factors are accountable for the loss of group members. First, the group consisted of a small number of core members who had formed themselves into an action group prior to the commencement of the current research project. The main goals of this group were to lobby for funding and action on the repair of the Ebchester Weir. Other members of the EWRG were identified through the drop-in session because of their general interest in the river and the impacts of the weir, and some were directed towards the group via the regional Rivers Trust after having expressed an interest in some form of river work. The 'core group' had pre-defined ideas about the shape and the goals of the project, and they dominated the first CG meeting. Two of the members with a more general interest in the river made the decision following the first CG meeting that the goals of the majority of the group were more specific than they had expected and did not wish to continue. Second, following the (earlier than anticipated) restoration of the weir, a number of the remaining participants felt that their objectives had been achieved and there was no need to continue further with the research process. This left a small group of three members who were participating not only in order to achieve restoration of the weir, but through personal interest of the modelling/research process and of the potential impacts of the restored weir. It should be noted here that all of the members who decided to discontinue their involvement, contributed valuable time and effort to the process in the early stages and the knowledge and experience they offered to the project was of value to the overall research process.

9.3.2.1 Group dynamics

The structure of the starting group can be considered as a combination of the 'natural' and 'assembled' groups, described by Conradson (2005, 134). Conradson suggests that focus groups may be one type or the other and that each has its limitations. The natural group (e.g. the core group in the EWRG) is one which is formed prior to the project (e.g. members of a social group, neighbourhood, etc.) and the familiarity within these groups may facilitate conversation and increase members' confidence (it may also mean that existing hierarchies come into play). In the assembled component of the group (the members interested in the river and the weir restoration, but not part of the initial founding group), members were more reserved and provided less input to the conversations (although when they did contribute, points were topical, valid and sparked healthy discussion). It is likely that the structure of the EWRG worked to enhance some of the issues associated with each type of focus group dynamic and that this may have worked against the overall success of the group. For instance, the reserved nature of the 'assembled' members, combined with the heightened confidence of the 'natural' members meant that most of the discussion was carried out between half of the group members. On reflection, the facilitation of the group could have been stronger in order to involve the 'peripheral' members more, although attempts were made to offer these members the chance to speak and comment, both within the CG meeting and privately, following the meeting. Another option to develop a stronger group would have been to allow enough time for the group to build trust together before addressing the topic at hand (Conradson, 2005, 135). However, the hybrid nature of the group made this difficult as those in the natural group wished to address the problem immediately and not delay the process with exercises that they did not view as necessary (Limoges, 1993, notes that participants often have a greater sense of urgency than researchers and require a process to be shorter and outcomes delivered sooner). Conradson (2005, 135) suggests that participatory processes such as this are prone to losing members and advises researchers to consider over-recruiting at the outset to allow for this. However, in this case, recruiting extra members to an already established group may have been the cause of the loss of those 'extra' members at the start of the process.

9.3.2.2 Unexpected achievement of goals

The greatest number of group members was lost following the restoration of the weir. During the time that the weir was being restored and the model being developed, a number of email communications were made with the members of the Competence group, to inform them of any small progress made and to maintain a 'presence', while work was conducted which effectively did not involve the other participants (this is considered to be an important aspect in maintaining relations and the trust that is being developed, e.g. Callon, 1999, 90). Some Competence group

members responded to these emails to acknowledge the progress updates, or make minor comments, others did not respond at all. At the time the preliminary model results were ready to be shared, communication had ceased with a number of the group members. Therefore, the meeting for the presentation of results (CG4) was held with those still interested. One member noted that for some members of the group, the repair of the weir had been the only goal and commented on the success of the participation in terms of those members:

“I mean here [this project] there’s got to be quite a sort of negative comeback on it, that you tried these things and it didn’t work, people weren’t interested in it, but the people who were interested were these kind of strange old guys who[laughter]” (M1, CG4)

The same member noted that numbers of those who would wish to be involved in the ‘mathematical aspects of river flow’ would be small. This suggests that the group saw the research project as something which they did not need to be a part of, and were interested only in the results, if those results were able to assist their case for weir restoration. In this context, it is understandable that some members did not wish to continue their involvement following the achievement of their primary goal.

9.3.2.3 Personal circumstances

On the same subject, another of the remaining members offered an alternative explanation for the loss of interest:

“But the question about whether people are interested also probably depends on the timing, and whether they happen to be busy doing something else” (M11, CG4)

This highlights the relative importance of such a research project to the different group members. All of those involved in the group had some sort of stake in the weir restoration effort (ranging from academic or environmental interests, to heritage values, to the practical use of the river), but the motive for involvement is likely to play a role in the level of interest under certain conditions. Those who had the academic and environmental stakes, held their interest for the duration of the project, they were specifically interested in the findings. Those who wanted the river to be restored to its former use had achieved their primary goals once the weir was repaired. This highlights the importance of a unifying issue for high-level participatory processes, which is discussed in the following section.

9.3.3 The motivational power of a controversy

The findings from this study highlight the importance of the presence of a controversy in achieving co-produced knowledge. A small number of authors have considered the need for a controversy in practical applications (e.g. Lane *et al.* 2011; Whatmore and Landström, 2011), and in theory (e.g. Callon, 1998, 1999, Latour, 2003; and Stengers, 2005), although in the majority of the literature cases studying participation and co-production, an issue is identified before public knowledge is incorporated. The need for public motivation is echoed in PAR theory. In true PAR, the research or investigation is driven by the community/public/concerned group themselves (Pain *et al.*, 2012) through their existing interest, motivation and desire for change. In much of the literature concerning participation in river management there is an assumption that participatory projects are led by external researchers and that participants are 'allowed in'. Even in those projects with very high levels of participation and public control, which achieve co-produced knowledge (e.g. Lane *et al.*, 2011), the process is instigated by researchers or managers. This means that power dynamics are already at play and may sway the direction of a project, it also means that assessments of the value of PAR processes in river management are very difficult to achieve objectively.

To address this issue in the Ebchester Study, a pre-formed action group was chosen as the starting point (although it is accepted that because the researcher instigated the research process, 'true' PAR may not have been achieved, but a number of the pre-formed group members voluntarily attended the preliminary drop-in session to voice their ideas to the researcher). An issue within the catchment and a group of citizens concerned about that issue was identified as a priority for this study, and research objectives were established as a fundamental aspect of the participatory process. The aim of this approach was to identify an issue that was of enough importance to a group to fuel passionate and enthusiastic deliberation about the topic. While the Ebchester Study did not give rise to a knowledge controversy in the purest sense (the group did not seek to change anyone's perception or view of the weir, the technical methods used to research the weir, and were not opposing decisions or management practices, but they had become frustrated with a statutory organisation from which they had hoped to secure support), the issue was of enough importance to unite the group in action to achieve their goal of restoration. The role of the research project, in their view, was as a tool to support their case in seeking funding and permission for structural work on the weir. While the group involved were very passionate about the restoration of the weir, that passion and enthusiasm was, understandably, lost through the early restoration of the weir, and with it much of the diversity of knowledge and understanding needed to address the EWRG objectives were also lost.

The driving force that a controversy provides, as demonstrated by Lane *et al.*'s (2011) work in Pickering (and also noted by Evans and Collins, 2008), draws attention to the damage that can be caused by participation done for the wrong reasons, or done without due planning and depth. In a number of the projects involved in the broad scale study, interviewees openly admitted that participatory processes were carried out simply because they were part of the protocol, or so that citizens would not object and 'not take [them] to court' (P1). P3 provided an example of the impacts that can occur when participation is offered only to some citizens, and when those likely to object are omitted from the process (in this case, those likely to object, did object, but did so through the media in retaliation for being excluded, consequently the project has become stalled). In the absence of an aspect within a project that unifies those involved, the participants can be made to feel their involvement is purely for the benefit of the organisation or researcher. This can lead to a sense of alienation, disinterest and resentment, particularly when the participants are asked to give valuable time to the project, or when contributions made are ignored. It is possible that once the weir at Ebchester was repaired, some of the group members felt that the only benefits that could then come of the research project, were for the researcher. Many environmental management organisations are now legally required to undertake participation in various forms (largely due to international and local legislative requirements (Walker, 2004)), but the motives of some have been questioned. For example, Slobbe *et al.* (2010) claim that consultation (at the least) has become institutionalised in regulations and Lane *et al.* (2011) suggest that participation, especially the kind which could be classed as Callon's PDM, is little more than legitimisation, criteria compliance and a 'box ticking exercise'. Rhoades (1998) suggests that some less optimistic authors consider participation to be 'a noble dream, but not very practical' and that all too often, what starts out as a 'participatory process' ends up being nothing more than a conventional hydrology or land-use study with participation in the project justification. Many advocates of participation support the process either because they believe citizens have a democratic right to be involved (normative participation), or because participation enhances a process (pragmatic participation), the latter often produces the higher quality decisions (Reed, 2008). Consequently, regardless of the motives for participation, care must be taken to employ it only when it is necessary, appropriate and achievable in order to avoid distancing citizens and producing superficial, weak results. The implications of ignoring this point are outlined in the following discussion.

9.3.4 Impacts of participant apathy

Although some group members participated until the end of the research process, by losing a significant proportion of the group, there were a number of implications for the outcomes of the

participatory project. First, there was a reduction in the diversity of knowledge and experience. Second, the social outcomes as a measure of participatory success were lessened. Finally, it is questionable whether the process led to a new and co-produced knowledge about the river around Ebchester Weir.

9.3.4.1 Loss of knowledge diversity

While the few members that wished to carry on to the end of the project provided very valuable inputs and knowledge to the process, some of the elements of the co-production approach were lost. This includes the diversity of knowledges contributing to a new understanding, and related to this, the loss of the opportunity for that diversity to lead to the validation both of the knowledges of other group members, and 'scientific' understandings. All of the group members brought to the project different types of expertise, based on the different form of relationship that each had experienced with the river over a number of years. Some important experiential bases were lost following the weir restoration, including fisheries, boating (recreation), cultural and long-term (dating back to the early 20th century) perspectives. As discussed in Section 9.2.2.2, the process of sharing knowledge within the structure of a competence group can assist in the validation of individual accounts as they are subjected to scrutiny from other group members (e.g. Callon, 1999; Lane *et al.*, 2011), so that the knowledge developed is one that is an amalgamation of the multiple experiences that have occurred within the group. Therefore, in the case of the Ebchester Study, such a validation process was possible in the first rounds (where ideas, goals and context were established), but in the later stages, comments made on the model outputs were unquestioned by the diverse group (although they were reasonable to the three remaining members). In a similar way, the validation of the model through group knowledge may be less rich than it would have been if there were more members available to comment on the outputs. A primary example of this is the research objective concerning depth upstream of the weir. This was to be investigated because those who boated in the pool required a minimum depth before the pool could be used. Without their input on the predicted pool depths, it is unknown whether those predicted were of any value to the boaters. Consequently, based on the importance that has been placed on model validation through the competence group, it could be said that in this case, the overall validity of the research outputs were compromised.

9.3.4.2 Absence of social benefits: a measure of participatory success

Furthermore, a decline in the diversity of knowledge within the group can cause a loss of focus on the group or community needs and the interests of the remaining members become dominant within the investigation. It is common for the success of participatory processes to be gauged by the social benefits achieved through the process (e.g. Carr *et al.*, 2012). One of the primary aims

of this project was to develop a research agenda with a group in order to make it context specific and applicable. By shifting the focus to that of a small proportion of the original group, this primary aim was at risk and it could be considered that the process, in this respect, was unsuccessful in achieving community goals. However, the goal of the lapsed group members was ultimately achieved through an alternative route, and the goals of the 'final group' were achieved (the original EWRG objectives were also addressed and results provided). In this case, then, the EWRG objectives were delivered, but interest in them was lacking.

Another social measure of participatory success is an empowerment of the participants to effect change through the research process (Breitbart, 2003; Kesby *et al.*, 2005; Cameron and Gibson, 2005), which should act as a vehicle for *social* change (Cahill, 2004). One of the original goals in this project, for the researcher and for the competence group, was to create a heightened level of knowledge within that group, of the potential implications and benefits of river restoration. The group intended to use the results of the research process to assist them in their campaign. However, the campaign did not reach a stage in which the results and the new understanding were required as a tool. The full involvement of participants at each stage is also considered an important aspect of participatory research (Breitbart, 2003; Pain and Francis, 2003), but again, was not achieved in this case. More sustained contact with the Competence group members during times of little output, and a more rapid response to the problem and EWRG objectives may have helped to maintain the interest of the competence group members, although it was noted that participation in the overall process was not an intention of many of the group members.

9.3.4.3 Failure to achieve co-produced knowledge?

Under Callon's notion of CKM (1999), it is important that a 'concerned group' is formed to deal with an issue, that the process involving this group creates a *new* knowledge and understanding of the issue, that the process addresses joint goals (around a matter of concern) for all involved, and that intermediaries (such as governmental catchment managers, because they are governed by regulatory constraints and internal goals) take a limited role in the process. In the case of the Ebchester Study, a group was formed around a particular issue of concern (although not a controversy in the purest sense). Goals were developed together to ensure that the focus was mutual within the group and intermediaries (primarily Durham County Council and the Environment Agency) were involved to seek advice on legislative issues, but were not part of the competence group. As for the creation of a new knowledge and understanding, a great deal of this occurred in the early sessions. By the end of CG 3 (most participants were involved to this point), an appreciation of the different reasons for requiring weir restoration had been developed and the group came to understand the reservations that some members had (such as fish

passage, important to those with angling and ecology interests). Based on the understanding of individual priorities, a set of *group* research objectives were established. Further joint understanding of the processes at play in the river and the historical context helped to develop a new image of the river and of the implications of restoration, for all members. The model results helped to further the understanding of the impacts of a restored weir and also of the model and scientific research processes. The process was deliberative and reflexive and allowed the knowledge developed within the Competence group to influence every stage. However, where this project deviates from Callon's ideology is in the final new understanding for all members. Although new knowledge was created right to the end of the process, the full concerned group was not involved in all steps. Therefore, losing a significant number of the competence group may mean that the process may not have been fully compliant with Callon's CKM.

When considered in the context of Gibbons *et al.*'s (1994) theory of Mode 1 and Mode 2 knowledge production, the Ebchester Weir project up to the point of CG 3, could be classified as having an application context, being transdisciplinary (experiential knowledge was provided in the fields of fisheries and ecology, as well as both scientific and experiential knowledge of flow and geomorphology characteristics), heterogeneous, reflexive with social accountability and having both novel and traditional aspects of quality control. The loss of members after CG 3 meant that the quality control aspect of the knowledge production became dominated by the traditional scientific approach, although there were some valuable contributions by the remaining members of the Competence group, which led to further model development. There was also a decrease in the level of social accountability overall, although the results were achieved based on the belief that they would be subject to scrutiny by the whole Competence group. The greatest impact, however, was on the level of transdisciplinarity, with the areas of expertise being reduced to those of flow, morphology and general use of the area. Therefore, there are some aspects of the process which are more reflective of the Mode 1 approach than Mode 2, following the loss of members. It should be remembered, however, that assignment to one of the two modes is not straight forward, and Godin (1998) recommended that projects are often hybrids of the two modes, with varying levels of (trans)disciplinarity, heterogeneity and context of application (see discussion in Section 9.2).

However, the loss of participants does not render the project void of merit, results or social application. It provided an insight into some of the important aspects of knowledge co-production, highlighting the importance of a matter of concern or controversy in such contexts (indeed, the moment the point of concern was removed, the dynamics of the Competence group

changed). The EWRG objectives were still addressed and on the whole, a deep and new understanding of the river and its potential responses to change was established. What is more, for the time that it was required, the competence group showed that knowledge and experience could be pooled effectively for the benefit of the whole group. Ziman (2000, 206) notes that negative outcomes are an essential part of any *evolutionary* process. Furthermore, Whatmore and Landström (2011) note that, in a similar project, should their participants have lost interest after one meeting, the process would still have resulted in new knowledge about public engagement and would satisfy a methodological experiment. The present study can be considered as both a successful methodological experiment (with the new findings of the importance of matters of concern and the functioning of competence groups when overriding circumstances change, in a 'live' (Whatmore and Landström (2011) situation, and as an environmental study of the river, in which a new understanding of the river, in historical, present and prospective contexts was gained).

9.4 Participatory benefits identified by the study

Despite the drawbacks highlighted through the loss of some Competence group members, and the questions that have arisen regarding the 'Mode 2' and 'CKM' theories, it is indisputable that participation, when conducted thoroughly and with the right motives, can lead to positive outcomes. This has been documented extensively (e.g. Clark, 2002; Lane *et al.*, 2011; Krueger *et al.*, 2012) and is also evident within the current study. The following sections will discuss the benefits that participation offered for river research in the present study, focusing on the co-production of knowledge, social learning, application specific research, and participation as a resource.

9.4.1 Knowledge co-production

According to Callon's CKM, co-produced knowledge should be developed within a group of people who are not necessarily qualified experts (in the traditional, scientific sense), but who share a concern which sets them apart from the wider public. There should also be close and constant collaboration between scientists and the lay concerned group members, the concerned group members should frame the knowledge from scientists through their own knowledge and questioning (Callon, 1999, 90), mutual commitment from all members, a common goal and a shared, dynamic resource pool (Wenger, 1998; Regeer and Bunders, 2009). Most importantly, existing knowledge should be challenged and reformed into a new understanding. With the exception of a mutual commitment (which was present at the outset), the Ebchester Study met

with these requirements. The group was formed from a number of community members who had a goal for the river and the weir and it was their shared desire for this goal that brought the group to life. Collaboration between all members of the group was close enough for the group to establish research objectives based on the provision of a pool of information provided by all members, and the division of tasks was appropriate within the group. Ultimately, a new understanding of the processes occurring in the river and around the weir was developed through questioning existing understandings, as well as assumptions and predictions that were made during the process (e.g. from the hydraulic model). The result was an enhanced knowledge of the processes occurring around the weir and an informed idea of how the river may react to the proposed changes.

Advocates of knowledge co-production highlight the importance of such a process for levelling the power hierarchies between institutions and social actors (e.g. see Irwin, 2008), meaning that science and society underwrite the existence of one another. This relationship was present within the Ebchester Study. The local experts' input was necessary to shape the focus of the research and direct the investigation towards the issues associated with the river and weir. In particular, knowledge of the historical characteristics of flow, sediment dynamics and vegetation growth/removal were key to the design of the EWRG objectives and the interpretation of model outputs. Through an understanding of the issues and research requirements of the community, the appropriate research tools were selected which offered flexibility in addressing research questions, and allowed effective communication and deliberation of preliminary results. Consequently, the research approach to the problem was context-specific, applied and reflexive, all conditions which are suggested as important characteristics for high-level participation and knowledge creation (e.g. Edquist, 1997; Slaughter and Leslie, 1997; Kondolf, 1998; Clark, 2002; Regeer and Bunders, 2009; Pahl-Wostl *et al.*, 2011). Within the Organisational Review, those projects which were able (and willing) to treat participants as equal members of the research group (Projects 5,7,8 and 9) reported higher levels of success in engaging the community and effectively using knowledge to address the research issue.

The Ebchester Weir project affirmed many of the benefits of high-level participation that have been previously cited. Examples of this include an increase in trust and understanding between participants (Pahl-Wostl and Hare, 2004), socially relevant objectives and outcomes (McDonald *et al.*, 2004; Petts, 2007), participant role in the quality control process (Henriksen *et al.*, 2009), better quality decisions of assessment, based on more complete information (Mostert, 2003; Harris *et al.*, 2012). However, it has also highlighted some less common attributes that the

process and outcomes may offer. These include an appreciation, on the part of the researcher, of the level of scientific detail required by the group. It may appear from participation literature that members of the public now have a democratic right to access all scientific information, and while all members should be open and transparent about their knowledge/information, it should not be assumed that all members wish to be informed of every scientific detail. In the case of Ebchester Weir, during the site visit, members of the Competence group were given the chance to view/use the dGPS equipment that was being used to collect DEM data for the model application. However, only one of the members wished to interact with the equipment. Some members appeared nervous about it and others were simply disinterested. What was of much greater appeal to every member of the group, was a discussion between all, about their experiences and observations at the site, which was greatly facilitated by the opportunity to point out specific locations, details and features. This group dynamic demonstrated the importance that the group members associated with a listener: someone who would hear their opinion and discuss it respectfully (something they expressed was lacking in communications with the Environment Agency). Another outcome of the process was to highlight the fact that the knowledge of the Competence group was not just an attribute to the process, but was, in fact, essential in the accurate representation of the processes at play around the weir (discussed in Section 8.3.2) and furthermore, the research needs of the group justified the entire research process.

Many of the positive outcomes suggested to be consequences of high-level participation (e.g. delegated power or citizen control, according to Arnstein's, (1969) classification, see Table 2.3) are features which are expected to be in place for the successful co-production of knowledge, in other words, what high-level participation may claim as outputs, true knowledge co-production considers to be pre-requisites. Examples include allowing participants to become aware of, and identify with their environment (House, 1999; Junker *et al.*, 2007), contribution to the definition and accreditation of scientific knowledge (Irwin and Wynne, 1996; Bucchi and Neresini, 2008), and the opportunity for participants to 'find a voice' (Macnaghten and Jacobs, 1997; Reed, 2008) (in this example, a concerned group are likely to have already begun to express their opinions and develop knowledge, but through co-producing knowledge, they may encourage others to accept that knowledge and respond to it, see Callon, 1999, 92). The reasons for this distinction between participation and co-production may be grounded in the contexts that lead to participation and knowledge co-production. The term 'participation' inherently implies that some authoritative figure allows 'outsiders' to have the privilege of being involved within a project, even when engagement is at the higher levels, whereas the basis of knowledge co-production (at least, for Callon), is that the commonality and identity within a concerned group moves that group to act

upon an issue of real concern and which has real and present impacts upon their lives. Therefore, in many cases of CKM, the concerned group may be the ones who instigate the research process, or at least bring the issue to the attention of researchers. The impact that such a process or issue has upon the group means that the members of that group have an existing knowledge/understanding/appreciation of the process or issue which is oriented, adapted and reformulated through the process. Another distinction between Arnstein's ladder of participation and Callon's classifications of knowledge production is that Callon maintains there is a place for the PDM in some situations and certainly, there remains an important role for traditional scientists. The notion of CKM is that all relevant actors work together to create knowledge, whereas the highest rung of Arnstein's ladder implies that the objective is the delivery of tasks (see Henriksen *et al.*, 2009) and that there is a stage at which the public become independent of the scientists.

The following sections outline some of the specific benefits highlighted by the Organisational Review and the Ebchester Study, which include social learning and focusing of research agendas.

9.4.2 Social learning

The varying definitions of 'social learning' are discussed in Section 2.4.4.1. To provide clarity for this discussion, however, social learning can be considered as an ongoing form of learning which can only be achieved through group interaction and does not belong to an individual but to the group. It can incorporate learning about a research topic and about the group dynamic through the research process and it should lead to a behaviour change by the group based on reformulation of understandings. It has been noted that the reflexivity inherent in social learning makes it a vital process for water management due to the complex nature of fluvial and environmental systems, and the complexity of their governance (e.g. see Tippett *et al.*, 2005). The present study has highlighted the benefits of social learning in a number of ways. First, the competence group learned of the different viewpoints and priorities of each member and through a process of divergent reframing (Emery *et al.*, 2013), reached a level of understanding in which they were able to develop a set of research objectives which were appropriate for the whole group. Bull *et al.* (2008) note that the ability for participants to recognise their interdependences, their differences and to deal with them constructively, is imperative to the process of social learning. Second, the areas of expertise of each member were quickly identified by the group in the first CG meeting and were used to frame discussions and subsequent questions. Third, the same research project can hold different meanings for different group members and it should not be assumed that all wish to contribute in the same way (discussed in Section 9.3). Fourth, in this case, the group preferred not to use props or equipment as a basis of discussion, but preferred instead to work through ideas verbally. Finally, the group were able to

comment on preliminary model results using their own experience and knowledge and therefore develop the modelling approach, while also using some of the model outputs to explain some of the processes they knew occurred, but could not explain. Points four and five, in particular, are reflective of the 'double-loop learning' concept described by Argyris and Schon (1978, see discussion in Section 2.4.4.1, single and double loop learning is also discussed by Maarleveld and Dangbégnon, 1999, and Tippett *et al.*, 2005) because having considered these points, the group was able to re-think methods and adopt a new approach (for point four) or re-design research objectives and model application (for point five). For the most part, the two main components of transformative and social learning (as outlined by Bull *et al.*, 2008), have been achieved. The first is *instrumental* learning, in which new skills and knowledge are obtained by a group, and the second is *communicative* learning which involves cooperation and solving collective problems. Pahl-Wostl *et al.* (2007) also note that there should be a dual-nature to the outcomes of social learning which involve both dealing with an environmental problem and the ability of the group to deal with social as well as environmental issues. It is undoubted that the process of the EWRG both helped the group to develop an understanding of the potential impacts of weir restoration, *and* to consider and accommodate the wider concerns of the group.

It has been suggested that social learning should be considered not only as an immediate impact of participatory research, but as a continuing alteration of behaviour towards responsible environmental citizenship, long after the participatory process has ended (e.g. Maarleveld and Dangbégnon, 1999; Pahl-Wostl *et al.*, 2007; Bull *et al.*, 2008). While this is a notable aim, whether it has been achieved for the Ebchester Study cannot yet be concluded. The first of three levels suggested by Pahl-Wostl *et al.* (2007), social learning during short term collaboration between stakeholders [local experts], is seen to have occurred (to some extent) within the Ebchester Weir project. However, the remaining two levels, in which there is a change in actor networks on medium timescales, and in governance structure on long timescales, is unlikely due to the small scale and context specific nature of the project. One possibility for the extension of the social learning from this project is a group of people which has now been established is empowered with the knowledge that they were able to effect change (although not entirely through the research component in question here). This confidence may enable the group to work towards change of a different nature or on a different scale, for future issues.

9.4.3 Focusing of research agenda

One of the most notable effects of a high-level participatory approach highlighted by the Ebchester Study (and to a certain degree, some of the projects in the Organisational Review), is the identification of appropriate and relevant research objectives. Leaving the final remit of the

study open at the outset allowed a project to be chosen based on the needs and concerns of the community around the River Derwent. There were two advantages to this approach: i) it increased the likelihood of finding a controversy or issue of concern that would, theoretically, bring a group of citizens together to engage enthusiastically in dealing with a real issue, and ii) it allowed the whole process to develop a research approach and a knowledge which is applied to a specific context (suggested by Gibbons *et al.*, 1994, to be one of the primary indicators of Mode 2 knowledge production). As a result, the research approach was tightly focused around the questions that mattered to those who would be affected by the potential changes, considered imperative by Eden *et al.* (2000) and McDonald *et al.* (2004). Walker (2004) notes that in addition to the environmental advantages of context-specific studies, incorporating focused questions from the start can assist in reducing group conflicts (as demonstrated through the Ebchester Weir project, where differences were explored and discussed in the first meeting). The social relevance which results from building research questions around community objectives can develop a sense of ownership among participants for that project, which can lead to long term support and interest in a project (e.g. Martin and Sherington, 1997; Wissmar and Beschta, 1998; Petts, 2007; Reed, 2008).

The research objectives for the EWRG were developed within the group, following discussion of each individual's knowledge and experience, including that of the researcher. Once an understanding had been gained about the expertise (in all its forms) that could be offered, the group was able to create a plan for research which was reasonable and achievable. Unrealistic goals were discussed but mutually sidelined, on the understanding that certain aspects would be difficult to investigate in the given time frame, or that other research questions should be prioritised, based on the overall requirements of the group. Petts (2007) notes that by assisting a group in understanding what issues are of greatest concern for the community and the group, a researcher or facilitator can enable them to 'inherently gain a better understanding of technical issues', by framing them in the context of their existing knowledge and through this, the group can understand together, the aspects of a project that are feasible for research (or in the case of Petts' project, implementation).

Ziman (2000, 165) highlights the difficulty in changing a research agenda once an investigation has begun. Beginning that investigation, then, on the right track and with the right focus, is of utmost importance if delays, elevated costs and unappreciated research are to be avoided. An exploratory approach to the research was not required because the knowledge of the competence group allowed us to focus attention directly on the aspects at issue, thus reducing

the overall time required for the research. The knowledge of the group about the historical behaviour of the river and weir also enriched the overall group understanding and provided information that simply could not have been obtained retrospectively or through traditional research approaches.

Information which can make efficient use of time and resources is of great value to those working under management and financial constraints. The novel approach to using participation as a *resource* was discussed in Chapter Four. It was identified through the Organisational Review that some of the OROs that operated on a small scale, and that were particularly constrained financially and temporally, but which had the flexibility to adapt their research and management approaches, had developed a view of participation as something of a resource. By harnessing and developing existing local knowledge, these OROs (primarily Projects 7 and 8), were able to focus their research priorities quickly and accurately. Furthermore, the knowledge of local experts was used to determine optimum spatial locations for management implementation and in some cases to continue with environmental work that had begun in their community months or years after the official project had ended (akin to the long term outcomes of social learning described above). A number of approaches were used to capture and develop knowledge in the study, but one which was particularly successful, especially for the small scale projects (including the Ebchester Study), was that of numerical modelling. The benefits and limitations of this approach are discussed below.

9.5 Participation in river management: case study of a numerical modelling approach

In his account of the three models of public involvement in scientific knowledge production, Callon emphasises that even within the most involved model (CKM), different actors may have different roles, and that knowledge produced in the lab (or through traditional approaches, in the case of river management, this often involves numerical modelling), is as crucial as it is in any other model of knowledge production (i.e. PEM or PDM). The distinction between co-production and the less involved approaches, is how that knowledge is then used, framed and re-defined based on the actions, questions and knowledge of the concerned group. Therefore, it follows that integrating a traditional modelling approach with discussions among a concerned group would be a productive way to develop a new understanding of the river, the model and the knowledge pool of that group. The Ebchester Weir component of this study aimed to determine how group members would interact with a model. For this reason, the hydraulic model to be used was

chosen carefully (see Section 7.1) to allow interaction by the group with the model itself, rather than simply presenting set results. This section addresses the appropriateness of the chosen model and of the overall approach for the Ebchester Study, the response of participants, their role in model validation, the positioning of the model results and the benefits of an involved approach for building trust within a group.

9.5.1 Participant response to a modelling approach

The model was chosen carefully for its simple user interface and data input approach, which allowed the implementation of new simulations to be applied quickly (in theory, on request by the group). Despite this, most group members appeared to consider (from the outset), the modelling process to be a specialist issue, in which they took no part. CG4, in which the group were offered the chance to view the model, its outputs and the process of using it, was poorly attended (as discussed in Section 8.2.1), although it is unclear whether this is as a result of the approaches for the meeting (i.e. the model), or the fact that the goal for most Competence group members had, at that point, been realised. However, the group members that did wish to continue into CG4, took a keen interest in both the modelling process, and the results it produced. Discussing the model results, with the aid of model output figures (e.g. see Figures 8.2 and 8.3) allowed a conversation to develop around the reasons for some of the outputs and the reasons for some of the observations made by the Competence group members. The members were able to take the results presented, and apply them to their own understanding of the processes. For example, the subtle changes predicted in response to changing the bar roughness (i.e. removing vegetation) were considered in comparison to the rate of vegetation growth. At first it seemed that there would be some merit in manually removing vegetation. However, when the model outputs were considered in the context of the case, and knowledge about vegetation re-growth rates was applied, the group questioned the value of such a task. As Callon describes, in this case, the experiential knowledge of the group was used to provide context to the model results and conclusions could be drawn based on the informed interpretation. As a result, the group were able to re-prioritise their research interests for the study. This example demonstrates the reflexive nature of high-level participatory research (described by a number of authors, e.g. Clark, 2002; McDonald *et al.*, 2004; Reed, 2008), which allows reformulation of ideas and objectives based on initial outcomes, and provides contextual application, as described in Mode 2 knowledge production theory (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001).

9.5.2 Appropriateness of chosen tools

The model used was able to answer most of the EWRG objectives set by the group, with an acceptable level of detail. Outputs of greater detail, particularly for the sediment dynamics

component could have been achieved through a more complex modelling approach (e.g. a 2D model such as Delft), however, a more complex system of analysis would have risked the exclusion of the group from that aspect of the process. With the 1D approach, the group members were able to view the model on a portable computer, and requests for application to new scenarios could be completed quickly, and with the group present. 2D models are often less mobile (due to licensing restrictions) and reformulation of scenarios would not have been carried out with the efficiency that the 1D model offered. Because of the nature of the study, a model approach that could be interactive among the group was considered to be of more benefit to the creation of a group knowledge, than a modelling process which would potentially segregate the scientific and social aspects of the research. The importance of an approach which effectively balances sound scientific methods and social knowledge creation has been documented (e.g. Petts, 2006; Henriksen *et al.*, 2009). Oliver *et al.* (2012), in their development of effective decision support tools for land management, note that priorities for the farmers involved, included the simplification of tools so that farmers are able to use the tools themselves (although there are other considerations for this, see Section 9.5.2), and provision of materials which explain outputs and results. Therefore, the findings of Oliver *et al.* (2012), and also of the present study, demonstrate that outputs must be of an appropriate level of complexity so that they are both legitimate and accessible. This is essential in order to achieve many of the benefits of using modelling in a participatory process, such as model validation by the group, the discussion of which is the basis of the following section.

9.5.3 Participation for model validation

Integrating the model outputs with local knowledge did not serve only to enhance the understanding of the group members, but as a fundamental part of the process (and one which cannot be separated from its impacts on the overall knowledge created), the assumptions and predictions of the model were validated (and the model developed) through the questions that were presented by the Competence group members. There are a number of examples of this, the primary one being the identification of the mis-representation of the restored weir shape, as a result of the Competence group questioning the predicted water levels for the restored weir profile (discussed in some detail in Section 8.3.2.1). Voinov and Bousquett (2010) discuss the impact of the different epistemological references found in participatory modelling. In natural science, the epistemological stance may be that 'a true statement is one which corresponds to real world facts', but from a social perspective, the epistemological stance may be that 'a true statement is one which is acceptable to the group', and Forrester (1999) suggests the best model to be the one which is most persuasive. Therefore whether a model is 'validated' (or evaluated) is

dependent upon the context. The HEC-RAS model, although evaluated in the traditional sense before it was presented to the Competence group, was 'socially validated' by gaining the trust of the Competence group members. Contributing to this trust was an understanding of what the model was and was not capable of, and an appreciation of the level of trust that could be placed in the model outputs. By understanding how the results were achieved, the Competence group members were able to make their own joint and individual decisions about what the results meant. In situations where knowledge co-production is a goal, validation should not be restricted to a process of comparing predictions with data, but also involves processes which make a model perform to achieve trust in that model and to solve a problem which is not solely technical in nature (e.g. Voinov and Bousquett, 2010).

Further analysis of the model inputs and outputs within the group raised questions about the model's ability to accurately predict peak flows:

“What is the origin of all the peaks? Is it controlled, like the release from the dam, or is it raining? And if it's rain, what do you know about the temporal profile of the rainfall because this will make a big difference” (M1, CG4)

It was noted that external conditions that are not accounted for within the model will impact observed flow hydrographs, but will not be represented in the predicted flow hydrographs, thus affecting overall predictions of hydraulic characteristics, an effect which is exaggerated at peak flows. This led to a discussion of the uncertainties and assumptions associated with any modelling approach and developed an understanding of the importance of careful interpretation of model results, particularly of not expecting the model to produce one definitive figure and working to that figure unquestioningly. For this component of the model, social validation and a heightened understanding of model uncertainties, and the influence of context on predictions were of greater importance than technical validation or 'perfect' predictions. The importance of using models for this purpose when working with stakeholders and participants is expressed by Voinov and Bousquett (2010). The Competence group members initially struggled to consider the levels of uncertainty as acceptable, despite them being within the generally accepted ranges for hydrological sciences (see Section 7.2.4). This difference in opinion highlighted the importance of ensuring that the expectations of the group are level, and understood by all. As Clark (2002) suggests, to scientists and managers, uncertainties are an accepted aspect of research, but to others (in Clark's case, policy makers, and in the case of this project, the competence group members), the uncertainties initially appear to deem the whole study void. It is imperative,

therefore, that the value of uncertainty, and the reasonable limits, are accepted by all parties, preferably before the process begins.

9.5.4 Scientific results in a social context

The experiential knowledge provided by the whole group at the start of the process assisted the remainder of the group during CG4 in the interpretation of some unexpected results. The model predicted that after a year of simulations (with any weir profile), degradation could be expected upstream of the weir and aggradation downstream. The opposite of this was initially expected, based on the knowledge of the impacts of a barrier to flow and of water falling from a height into the downstream section. However, while reviewing these results, the large flood event experienced in September 2008 (and of great significance to many of the group members), was highlighted within the year of flow data for the sediment simulations. The Competence group had established, in the early stages, that flushing events (such as floods) often removed much of the fine sediment from the bed of the upstream pool. All of the aggradation and degradation that occurred within a year of simulations happened within a day of this large flood event. The experiential knowledge of the flushing events led the group to the conclusion that the increased flows upstream of the weir caused the degradation, and that sediment in transport during the storm was deposited downstream as the flow entered a deep pool (see Section 8.4.2). As suggested by Callon (1999, 91) and Petts (2007), the pooling of a diversity of knowledges can help to reposition scientific results and lead to new interpretations, and as Whatmore and Landström (2011) noted, experiential knowledge can be informative, even after group members have parted from a project.

9.5.5 Model use for rebuilding trust

An unexpected outcome of the modelling approach was the highlighting of group dis-trust in certain management organisations. It had been noted in earlier meetings that the group had attempted to obtain environmental data from a specific organisation, without success and that the group maintained a feeling of exclusion and that efforts to assist in their goal had been promised but not delivered. This feeling carried through into the current process, as when input data for the model were said to be sourced from the organisation in question, the group members assumed a lack of accuracy in the data and in their mode of calculation (despite the methods used - rating equations for stage on a given cross section - being standard protocol within hydrology studies). One member considered the approach to have been adopted because it “makes the maths easier”. Sturgis and Allum (2004) suggest that trust in expert claims or in an organisation can affect a person’s attitude towards science. In this case, the feeling of the group that it had been let down by the organisation had resulted in their lack of trust in any aspect of their work.

In order to re-build trust, Wynne (1992a) suggests that those who have lost trust should be allowed to examine science for themselves and to be involved in the generation of knowledge. Although the current process has made some progress in offering to the Competence group the opportunity to re-build trust in scientific practices, the same treatment would need to be offered to them by those who initially caused the loss of trust. However, it is hoped that the process has developed the confidence of the group sufficiently to communicate with the organisation in question.

9.6 Participation and knowledge co-production in river management: final questions

The above topics of discussion lead to a number of final questions about the projects studied here, and about the process of participation and the co-production of knowledge. First, does an *optimum level* of participation exist, and does this change with the context of a project? Second, should high-level participation be universally adopted for river management and if not, what are the alternatives? Finally, can high-level participation work, and what is the value of co-produced knowledge for river management practice? Each of these issues is discussed below and the chapter is concluded with a summary of what the study has taught researchers and managers.

9.6.1. Does an optimum level of participation exist?

Review of a number of participatory management processes (in the broad scale study), and involvement in a local scale participation research effort have highlighted the range of participation levels used by different actors, and in different contexts. As discussed earlier within this chapter, and in Chapter Four, level of participation varies according to a number of factors including scale of project, motivations and rationale, available resources, and management constraints. High-level participation was most commonly found in smaller scale projects that had fewer managerial constraints, but that were limited in terms of time and funds. Level of participation also varied within projects, depending upon the project remit and the goals for particular stages. The overall production of knowledge between scientists, managers and relevant members of the public was rare. Collins and Ison (2009) note that a fixation on classified levels of participation, such as those presented by Arnstein (1969), can constrain the way a person or group thinks about participation and learning, as well as limiting the purposes that are ascribed to the participatory process. A levelling of knowledge hierarchies that leads to new forms of learning and re-framing of the issue would be a potential alternative (Collins and Ison, 2009). However, this process again returns to the higher level involvement that is necessary for such

approaches to learning. The difference here is that such levels of involvement are adopted for reasons such as the desire of a heightened and context-specific understanding, rather than because an actor feels obliged to select a level of participation from a list and apply it to their study. In this vein, the motives for participation and the overall project goals have been described by some (e.g. Rowe and Frewer, 2000; Reed, 2008) as the factors which should be prioritised in selecting participatory approaches. Another key aspect which demands consideration is in selecting the appropriate level of participation for all involved. It is likely that optimum level of participation varies for different actors. For example, catchment managers may prefer a consultation-style process, in which information can be sourced from participants, but in which the catchment managers retain total control and are able to decide which aspects of information are included or omitted. Conversely, a community action group may wish to be part of a process such as delegated power, in which they have significant authority to sway decisions, but still have input from researchers or managers. The difficulty lies in selecting an approach which meets the needs of all actors, without leaving all actors feeling dissatisfied with the process. This is something which must be considered in the context of each individual project and there is no pre-defined solution.

Within the Ebchester Study the final level of participation is positioned somewhere near the top of Arnstein's ladder, perhaps delegated power, and the outputs share some similarities with co-produced knowledge as described by Callon (1999) or Gibbons *et al.* (1994). Despite this, knowledge production and the research process were less involved than were expected at the outset. The initial idea had involved members of the group participating in data collection and being more critical of the model and its outputs. A combination of practical constraints and a loss of interest resulted in the absence of these features, so although there were some informative outputs, it was hoped that the group would have been more engaged with the process. The weir project was small in scale, not constrained by any institutional requirements and was relatively unfettered in terms of time, equipment and funds (due to technical support offered by the research institution). When a project that is highly flexible in topic, methodology and remit struggles to achieve the desired level of participation, it is easy to comprehend the reasons for which projects with specific aims consist of much lower levels of participation. This finding can shed some light on the reasons for so many theoretical suggestions of high-level participation and co-production, but the few practical cases which truly apply high-level participation, or achieve truly co-produced knowledge. In theory, the concept is attractive and rewarding, but in practical situations there are complications (considered in detail throughout this chapter and Chapter Four), which mean that unless the process is carried out with full and proper commitment from all

involved, the results can be superficial. Therefore, a thorough understanding of both the project goals and the project capabilities (i.e. in terms of both knowledge and resources) must be achieved before the participatory approach can be specified.

9.6.2. Should high level participation be universally adopted?

This study, and particularly the broad scale component, has demonstrated that high-level participation and co-production of knowledge are logistically difficult to achieve on a large scale, and that simply 'scaling up' approaches taken at the local level is not always possible. Based on definitions for higher level participatory approaches, particularly citizen control (e.g. Arnstein, 1969; Mostert, 2003: see Table 2.3), it is clear that large scale organisations with a remit for national or regional river management (often flood risk protection), cannot hand decision-making powers to members of the public, whose knowledge is often locally based. Instead, public knowledge ought to be gathered for a number of locations and those with the experience to understand river processes should be responsible for interpreting local information on the regional or national scale and ensuring that impacts are linked up (as discussed in Section 9.2.2.2). Therefore, based on the evidence gathered in this study, it would seem that high-level participation and knowledge co-production may not be appropriate for all river management studies, and knowledge co-production, particularly as Callon (1999) describes it, which focuses around a knowledge controversy, should be reserved for situations in which trust needs to be rebuilt or there is a matter of particular concern to a group of people.

That is not to say, however, that public knowledge should not be incorporated. Perhaps more appropriate for the large scale projects, particularly those which have fixed remits, would be the goal to achieve *social learning* (e.g. Robinson, 2003; Tippett *et al.*, 2005). It is recommended that larger scale organisations look beyond an individual project when considering participation and adopt an approach which can lead to double-loop learning (as described by Argyris and Schon, 1978), to utilise local knowledge for application to the specifics of a project, but also, and perhaps more importantly, to instil social change both within and outside of the organisation itself. This approach may seem like a large commitment, and may not fit well with current models of management in which structures are often set for application in a number of locations and or timescales, or where systems are designed to be predicted or controlled (Pahl-Wostl *et al.*, 2007). Furthermore, the approach may introduce an element of uncertainty into the process in terms of having to re-think strategies based on preliminary outcomes and re-assign resources during the project. However, as suggested by a number of authors (e.g. Maarleveld and Dangbégnon, 1999; Tippett *et al.*, 2005; Pahl-Wostl *et al.*, 2007), a process which leads to social learning can have multiple long-term benefits for river management organisations by increasing levels of trust

between actors, making decisions more robust, challenging both managers and other participants to re-think their approach to a certain issue, and by increasing the organisation's ability to deal with uncertainty and change. The latter point is of particular significance to water managers due to the complexity of hydrological systems, ambitious demands enforced in current legislation (e.g. the WFD: Tippet *et al*, 2005) and the ever-changing uncertainties brought about by climate change. A learning approach which provides organisations with adaptive capacity and a level of resilience will assist in long-term, effective management of water resources and river systems. Furthermore, Pahl-Wostl *et al.* (2007) suggest that social learning can occur on three scales (the short-term, collaboration scale; mid-term, actor network scale and long-term governance scale), which are interdependent and iterative, meaning that knowledge and development at all scales can be incorporated in an appropriate manner.

9.7 Chapter summary and lessons learned

9.7.1 Summary

This chapter has outlined both the positive and negative aspects of participation, at a range of scales and considered the practical implications in the context of more theoretically based literature, while aiming to determine whether the two are interchangeable. A number of questions which remain unanswered within current literature on participation were addressed, based on the findings of this study. While there is much literature supporting the use of higher level participatory approaches, their actual employment in practical situations is less common. Assigning a level of participation or mode of knowledge production to certain projects was shown to be difficult, based on analysis of the participatory approach used within the Organisational Review and the Ebchester Study. It was also found that using the same participatory approach can lead to very different outcomes and levels of success, and this was primarily based on the context of the project, and the motives that were associated with the individual or group carrying out the procedure. It was common for a number of different approaches to be used within the same project, depending upon the required outcome of the participatory approach for a specific component of a project. Scale was found to be the dominant factor controlling level of participation and the achievement of knowledge co-production, within the case studies analysed in this thesis. Scale needs to be of an optimum degree so that there is sufficient expertise and diversity within a group to fully assess issues and consider relevant knowledge, but scale also needs to be small enough that logistical constraints such as number of people affected/involved do not hinder the process, and so that experiential knowledge, being inherently local, can be

applied effectively to the study of a specific site. Furthermore, scaling up processes used at the reach to be applied at the catchment scale should be done with great caution, if at all.

Another major obstruction to thorough and enthusiastic use of participation for many of the groups in this project was the perceived acceptability (or unacceptability) of local or experiential knowledge, and how its use can be justified in the natural sciences. It is argued here that for co-production, it is the very process of a joint knowledge creation: the diverse expertise within a group, the questioning of assumptions and the re-framing of existing knowledge, that serves to 'validate' the knowledge offered and produced. Moreover, experiential knowledge is often used to fill information gaps where data are difficult to obtain, or when a historical perspective is required, and it has been argued that the long-term and context specific nature of experiential knowledge makes it more appropriate in researching a context-specific issue.

The assumption that people desire to be involved in every research process was examined. The Ebchester Weir study highlighted that this is not always the case and the implications of assuming it is so include the potential collapse of a project which is founded on the creation of knowledge between a mutually committed group. Factors such as group dynamics and participant motives must be considered when establishing a research group in an attempt to avoid losing members during the process. Losing such members can result in the lessened diversity of knowledge contribution and difficulty in the validation and justification of the process. It can also mean that the social aims of participation, such as the empowerment of groups and members to have confidence in their knowledge and use that knowledge, can be absent. The importance of a controversy in unifying group members and motivating them to remain part of the knowledge production process was demonstrated through the Ebchester Study. It was also noted, however, that social (and sometimes physical) knowledge can still be developed as a result of the loss of group members.

The study also highlighted a number of benefits associated with high-level participation. These include the co-production of a context-specific and applied knowledge which can be used to address a particular issue or matter of concern for a group of affected people. A pooling of experiential knowledge and its use to question and to frame scientific knowledge can result in a more detailed and deeper understanding of processes within a system and how they may respond to change. For the Ebchester Study, it was also demonstrated that the process of knowledge co-production can assist in model development and result in the social validation of scientific tools such as hydraulic models. Other significant benefits include the focusing of research attention and development of relevant research objectives, as well as a wider social learning about the

river, the process of participation, and behaviour towards river management practices. A number of key lessons have been highlighted by the study and these are summarised below.

9.7.2 Lessons learned

A number of key lessons were learned as a result of the study as a whole. The results of this study have demonstrated that there is certainly a requirement for participation in almost all aspects of river management, but that the nature of the participatory approach should be determined by the context of the issue and not by general regulations or guidelines which assume higher level participation is invariably the optimum approach. Careful consideration of the goals, remit, resources, who is affected and who can contribute must be applied in selection of the most suitable approach. It is also appropriate for different participatory approaches to be used for different components of a project, even at the smallest scale, as was demonstrated through the Ebchester Weir study. However, this does not mean that reasons for doing participation should be solely pragmatic, there should also be normative rationale for selected participatory procedures which ensure that those who are affected, or those who have valuable contributions to make, have the opportunity to be involved.

The role of the participatory process was shown to be as important for the researcher as it is for the non-certified experts, or the public, a perspective commonly ignored in participation studies (Petts, 2007). Researchers or managers can learn a great deal about the applicability and accessibility of their work when it has to be shared with and justified to external participants. Knowledge created in a diverse group can help to challenge previously unquestioned process assumptions and model predictions, as well as create a mutual understanding within a group of varying priorities and needs. In this way, the outputs of the research process can be socially as well as environmentally relevant. Additionally, researchers should carry forward what is learned about social dynamics within river management processes and use this information to inform and improve future projects from the outset.

The Ebchester Weir project showed that it is imperative to examine small details of a participatory process in the planning stages. Although the process is designed to be reflexive, and able to deal with change as the project progresses, being mindful of the context and motives of those involved can help to avoid later complications. In this case, acknowledging that the main priority for many of the Competence group members was the repair of the weir, and being aware that there was a chance (albeit a small chance) that the weir would be fixed before the research was completed, may have assisted design and planning. For example, the research and data collection process may have been brought forward and prioritised over the broad scale study in order to maintain

interest to as late a stage as possible. However, the loss of interest of some members also produced an insight to the fragility of the group dynamic and of what is dependent upon that dynamic.

Chapter Ten

Conclusions and study implications

10.1 Synthesis: an interdisciplinary, participatory approach to river research and management?

This study aimed to identify and assess the context and the use of innovative research approaches which focused on the incorporation of environmental knowledge in all its formats. Such an aim required a process of knowledge sharing and deliberation which could lead to the co-production of knowledge between a group of concerned citizens, who possess between them a diversity of expertise. In order to address the aim, a two-tiered approach was adopted which consisted of i) a review of participatory approaches currently adopted by river management organisations in the UK and Europe (the 'Organisational Review'); and ii) an interdisciplinary, participatory study, which was nested within the bigger project and which produced its own research questions and findings (the 'Ebchester Study'). The approaches taken within this study are discussed below, followed by a summary of findings (for the overall project and for the research questions specific to the Ebchester Study). The role of participation and knowledge production in river management and research are then discussed, based on the study findings, and the chapter will conclude with a review of how this research field may develop, in light of the outcomes.

10.1.1 Research approach

This study used an interdisciplinary integration of social and physical science methods, and a participatory approach, consisting of two stages of research to consider the role of participation and knowledge production in river studies. The first part of the study (the Organisational Review) utilised traditional social science interview methods to gather information about the current approach to participation among river managers, and to inform the participatory research in terms of common issues or misconceptions around participatory approaches. The second aspect of the study (the Ebchester Study) involved an interdisciplinary and participatory approach which

allowed a research project to develop focused on the priorities of, and conducted in conjunction with, those affected by changes to the river.

The *interdisciplinary* nature of the research approach has allowed an improved insight into the physical, social, environmental and economic aspects of river management, and has highlighted the importance of a holistic perspective to river research and management. It is widely accepted that river research must be holistic in the spatial sense (i.e. consideration of physical processes both at the catchment and the reach scale). However, a holistic viewpoint was also required in terms of the research context and application. This means that it was not sufficient to consider only the physical and environmental aspects of a river, when social and cultural aspects both affect and are affected by decisions made concerning a river or reach (e.g. Hobbs and Harris, 2001; Blackstock *et al.*, 2007). It was only through an appreciation of the full spectrum of river uses and influences, that an improved understanding of management implications could be achieved.

The *participatory* aspect of this project encouraged the production of a new and joint understanding of river processes in a specific context through the integration of a number of forms of knowledge about the river, which included local, experiential knowledge, historical knowledge of river behaviour and response to change, scientific knowledge in the form of physical data such as flow and morphology, and technical knowledge of the use of hydraulic modelling to predict river response to change. The deliberation of the changing knowledges at every stage of the process allowed a reflexive response to the new knowledge, and the new foci, continually being created. The result was an understanding of river processes, specific to the reach in question, and increased confidence of the Competence group in the knowledge created (as a consequence of them being a part of that creation) to conduct further research and action in the future, if required.

The process also engendered an understanding of the assumptions often made in participatory research, which can hinder or damage the overall outputs of such an approach. The impact of these assumptions has helped in reflection upon the appropriateness of participatory research in various contexts, and in consideration of the implications of an ever-growing body of literature which calls us all to be advocates of public engagement. A brief summary of the research findings is provided below, and a review of the implications of the findings follows.

10.1.2 Summary of findings

A number of research questions were presented in Section 2.6 and were used to shape the research process. How this study has contributed to answering these questions is outlined here.

1. What approaches to participation in river management currently exist, and are the different approaches identified characteristic of certain contexts?

Opinions about the value of participation in the river management process varied among river management organisations (OROs) but appeared to be affected by a number of factors including scale of organisation or project, resources available to the river managers, and ultimate goals. The view held by a river manager or organisation, of the value of participation, was found in this research to have profound effects on the approach used and levels of success. Many of the larger, statutory organisations (OROs) struggled to conduct high-level participation (such as Arnstein's citizen control, delegated power, or partnership (Arnstein, 1969)), while the smaller, voluntary OROs with a more flexible remit, and tighter funding constraints were found not only to use higher level participation, but to value its use as a tool in focusing and achieving research or management goals. The issue of low uptake of high-level participation identified by the Organisational Review was used to shape the focus of the Ebchester Study and determine the value of offering participants a great degree of control in setting a research agenda.

2. Can innovative approaches to river management practices be developed to deliver more socially relevant outcomes, helping all members to learn about the environment and the process?

a) Which methodologies can be used to bring together scientific and experiential knowledge?

b) Which actors should be involved?

This research has shown that an approach to river management or research which allows relevant participants to shape the research objectives can lead to a process which is grounded in the application context, and therefore potentially be socially as well as environmentally relevant. Furthermore, contribution and deliberation of a range of knowledge types, sourced from participants with diverse experience and backgrounds can lead to the production of a new knowledge which belongs to the entire group in which it was created. This group may benefit from further learning about the topic in question and use the 'non-tangible' benefits of the process (such as increased confidence, understanding of the implications of certain aspects or issues in river management, or the way in which certain group members interact with knowledge) to change future attitudes or approaches to an issue (this is termed 'social learning' and applies equally to the certified expert and to the rest of the group).

The methods used to engage participants must be selected carefully and a balance must be found between achieving 'robust scientific data' and methods which are accessible to all participants. Research tools which are found by some group members to be intimidating, or uninteresting can exclude parts of the group and affect the focus and nature of the research. Additionally, an environment in which all members feel comfortable, as well as a unifying cause for their participation, have proved essential in the successful engagement of participants. If these elements are successfully provided, then the pooling and questioning of individual knowledge from members with a driving cause, combined with a process which is reflexive enough to adapt to developing perceptions of an issue (in response to the knowledge produced) can effectively lead to the improved understanding of a topic or issue. However, this approach is not universally appropriate and the specific context of a project should be considered carefully (discussed fully below). Careful selection of participants is necessary to ensure prolonged participation, and a controversy or unified cause can help to motivate a group and lead to constructive deliberation. However, as this study has shown, participants' situations and project context can change unexpectedly, leading to a change in group dynamics.

3. What role can experiential knowledge play in problem solving and how can it be incorporated into the research process?

a) Can practical examples of river management be applied to the knowledge frameworks described in the Science and Technology Studies literature?

b) Why has there been limited use of controversies in creating improved knowledge in river management?

Experiential knowledge was identified by both the Organisational Review and the Ebchester Study to be highly valuable in river research and management. In a number of cases, perspectives were offered by participants which could only be achieved through experience with the social and cultural aspects of a river or catchment, or from a long-term and regular relationship with the river. It is these perspectives which are able to frame and contextualise the scientific knowledge provided by a manager or researcher in order to achieve a knowledge base specific to that catchment or reach.

Integration of the different knowledge types can be challenging and requires a process which is iterative and allows the group to reflect on information, question it, and subsequently adapt the approach taken to determine the information (where necessary). This process should be considered as a cycle which is repeated until all group members are satisfied with the way in

which the knowledge has been produced, although this requires a common goal and a fair and grounded attitude from all members. The integration of knowledge types was illustrated in Figure 1.2, which can be expanded here (Figure 10.1) to incorporate an iterative process which allows the original knowledge types to be deliberated and re-framed to produce a new form of knowledge (co-produced). In the Ebchester Study, the processes of deliberation and re-framing served to broaden the understanding of the group members, in relation to perspectives and agendas of other members. It also allowed the practitioner (and researcher) to gain an understanding of the needs of the group and the wider community. Furthermore, the iterative approach used in model development led to a model which was validated both socially and scientifically.

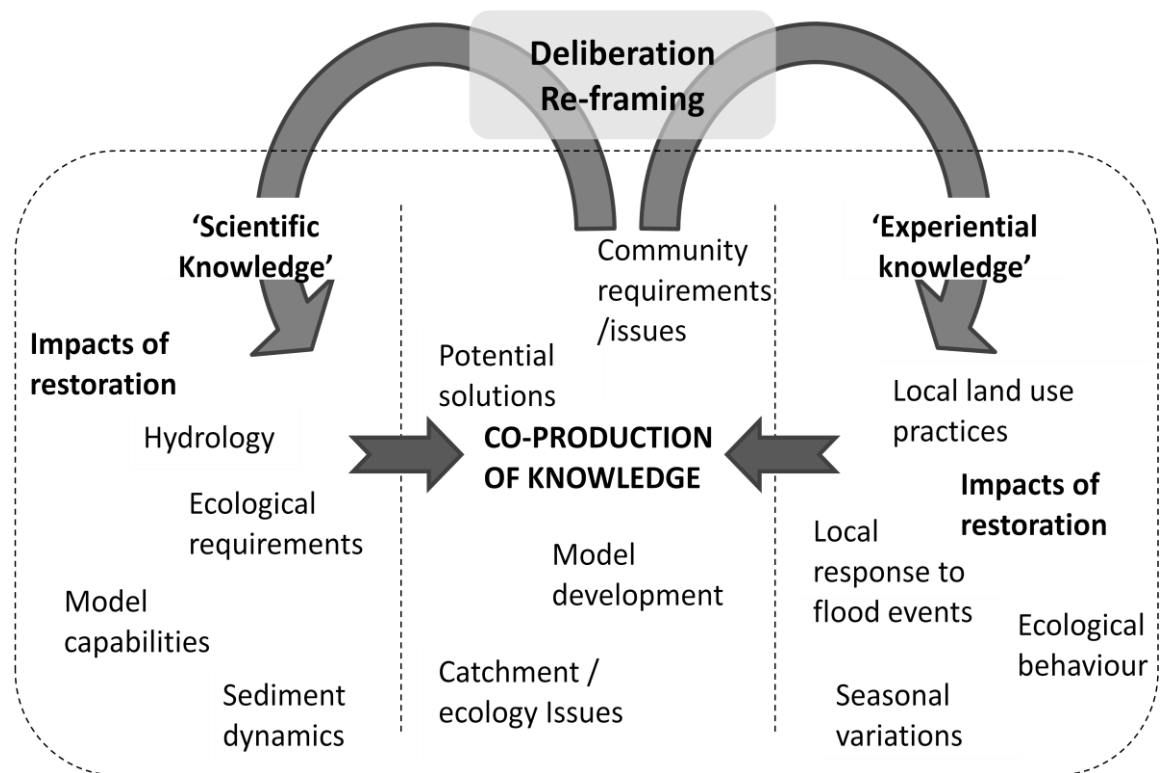


Figure 10.1 Development of original 'Unity of knowledges' figure (Figure 1.2), in which deliberation and re-framing become the central components of the iterative process. Through the deliberation and re-framing of all 'original' knowledge, a new knowledge is formed, which is owned not by an individual, but by the group

There have been many attempts to classify and define the knowledge production process, and to describe how a socially relevant knowledge production process may take place (e.g. Gibbons *et al.*, 1994; Callon, 1999). This study has questioned the practicality of defining the knowledge production process in case study examples, due to the multiple requirements placed on one type

of knowledge production. It has proposed that in reality, an amalgamation of the different levels or modes of knowledge production exists within one process, and that the dynamic natures of research and knowledge production mean that approaches change continually. Figure 4.2 was designed, based on the results of the Organisational Review, as an alternative to Callon's (1999) Co-production of Knowledge model (Figure 4.1), with specific focus on river research and management activities. Following the Ebchester Study, and the analysis of a broader range of case studies, this figure can be developed to account more fully for the different actors involved (see Figure 10.2). The categories of 'affected public' and 'interested public' may be too distinct and may overlap either with each other or with the category of 'local experts'. Therefore, these categories may be changed to a 'spectrum of publics', in which members of the public may be involved with a project to varying degrees through time. Furthermore, the nature of 'managers' within river management is also variable within and between projects, and will have an impact on the degree of interaction between the public and the manager. For example, voluntary river management groups (as described by Cook *et al.*, 2011), are likely to offer a greater degree of involvement than regulatory managers (e.g. EA, DEFRA). This dynamic should also be considered when aiming to categorise participation and knowledge production processes.

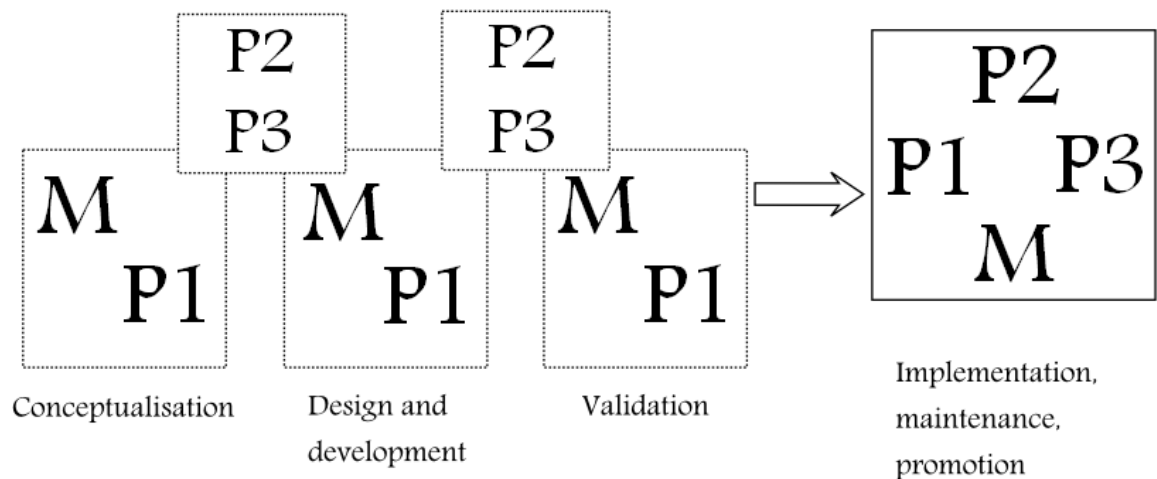


Figure 10.2 Model of participation for use by catchment management organisations at different project stages. This model was developed based on results of the Organisational Review, the Ebchester Study, and the joint analysis of the two studies. P1; P2; P3 = Public 1; 2; 3; M = Managers. Note: Public 1 = members of the public who are affected by, and contribute to, the knowledge production process; Public 2 = members of the public who do not contribute to the knowledge production process, but have a stake, are affected by, or are interested in, the issue around which the knowledge production process is based; Public 3 = members of the public

who have limited involvement or stake in the knowledge production process. Members in group P1 have the greatest level of involvement, but the members which make up this group may change throughout the project. Members of groups P2 and P3 may also vary. They have less involvement but are engaged at various stages, either as part of a process (e.g. conceptualisation), or between two processes. Managers, while considered as one group here, can vary within and between projects (see above) and may include intermediaries or scientists. Therefore, their role should be considered with respect to the nature of the management organisation

Knowledge controversies present themselves as effective environments in which a group of people may be motivated to work together to understand and address an issue. However, the circumstances leading to a controversy and the likelihood that all relevant and necessary members of a group are able to contribute to the process mean that the creation of such competence groups is rare. This is particularly true for river managers (rather than researchers) who often have pre-defined objectives and structured participatory approaches which must be adhered to. Under such stringent conditions, the members of a concerned group are unlikely to be effectively engaged or comfortable in participating. The role of intermediaries or managers in the constructive use of a controversy is therefore questioned (Section 4.4) and again caution is advised in choosing the appropriate situation for high-level participation.

4. How important is scale? Can the principles outlined in the suggestions for the co-production of knowledge theories be scaled up and are approaches transferable to new sites and new problems?

Spatial scale has been shown to be the major controlling factor on some participatory approaches. The process by which experiential knowledge is gained and co-produced knowledge achieved, are inherently local. Scaling up of the approach is not a simple process and the results of this study suggested that knowledge co-production is employed in the most appropriate environments – ideally, that is one which is local enough to involve all participants fully and which can develop trusting and productive relationships. However, to suggest that co-production is only valid at reach scales may be seen as an invitation to large organisations to continue to work from the top down, which would reinforce power issues discussed previously (e.g. Section 2.5.1). What is required, therefore, is a change within the structure of policy and decision-making which enables large organisations to more effectively incorporate the knowledges and concerns of the wider community. This provides an avenue for continued research beyond this thesis.

The findings of this study have been used to consider the role of experiential knowledge, participation and co-production in river management and research. This is discussed in the following section, in which a number of recommendations are made concerning the process of participation.

10.2 Participation and knowledge production as a beneficial approach to river management?

The findings of this study have allowed a number of reflections and recommendations to be made regarding the use of a participatory approach to river research and management. Each is discussed below and a table of recommendations for practice has been provided (Table 10.1).

10.2.1 Appropriate level of participation

Although descriptions and recommendations of higher-level participation are common within theoretical literature (e.g. Gibbons *et al.*, 1994; Callon, 1999; Ziman, 2000), case studies of such an approach and of true knowledge co-production, in the river research and management field are uncommon. The multiple participatory approaches that occur within a project, the range of definitions applied to the same participation level and the difficulty in categorising practical participatory procedures were highlighted in Section 9.2.1. These observations have led the author to conclude that participatory efforts should not be labelled as a distinct approach or method which apply to a fixed group of people or a fixed agenda, rather, they should be seen as a fluid process through which knowledge of river management (in many forms) is developed, created and shared. Furthermore, success of such approaches should be measured by the changes they instil and the benefits brought about to the *environmental and social* communities that they are designed to assist.

10.2.2 Appropriate scale at which to conduct participation

The selection process for the appropriate level of participation should consider, to some degree, the scale at which the participation is being carried out. It has been shown that higher level participation is currently difficult to apply at greater spatial scales (e.g. sub-catchment and catchment) and that the outcomes of a high-level participatory process are generally strongest at the local (reach) scale (see also Hughes *et al.*, 2001; Adams *et al.*, 2004). Therefore, the widespread claim of 'a higher level of involvement is unwaveringly the most appropriate' should be considered with caution. Each project must be considered in its own context, and only through a thorough understanding of the needs, resources and dynamics of an environment (including its

community), can the appropriate level of participation be established. It should not be assumed that 'one size fits all' (as described by interviewee P8 in the Organisational Review), but that every project is unique and requires a fresh perspective.

10.2.3 Dealing with uncertainty

Uncertainty presents itself in many forms, including in the basis on which experiential knowledge is formed, and also in scientific data collection methods and process representations (Krueger *et al.*, 2012), e.g. hydraulic modelling. Within this study uncertainty in all types of knowledge has been considered. In the modelling component, the model was tested for sensitivity to spatial and temporal resolution, and evaluated to ensure a satisfactory level of flow prediction (Sections 7.2.3 and 7.2.4). Uncertainty in experiential knowledge was considered in Section 9.2.2.2 where it is demonstrated that the validity of knowledge produced within the group can be justified through the production process.

There remains much scepticism, within the field, concerning the validity of experiential knowledge and its application to processes which inform catchment decision-making (Eden and Tunstall, 2006; Reed, 2008). The research in this study has highlighted such scepticism among river managers (and also researchers, to varying degrees). However, it is argued here that a participatory approach does not expect river managers or researchers to unquestioningly accept the experiential knowledge of an individual. Rather, it requires managers and researchers to consider and value the process by which co-produced knowledge is created. Furthermore, the knowledge provided by traditional scientists is also deliberated and subject to critical reflection (the primary advantage to a CKM approach, as suggested by Callon, 1999). The deliberation, questioning and re-framing of scientific knowledge by a community with a vested interest serves only to strengthen the overall knowledge created, and to increase the trust in that knowledge, not only for the non-certified experts, but for the certified experts also. This observation reiterates the importance of scale for the co-production of knowledge and the difficulty in 'scaling-up': the deliberation process can only be effective when all those who have contributed information and views are given the opportunity to challenge and accept the new knowledge.

10.2.4 The implications of participant apathy

Participants may remove themselves from a process for many reasons, and this study has shown that members may be lost even when a project is established carefully in order to engage members through a joint goal. Therefore, it should never be assumed that a project framework is stable. Those undertaking a participatory process should be prepared for the situation to change at any stage, and a reflexive attitude will enable practitioners to capitalise upon unexpected

situations. This point further strengthens the argument that participatory approaches should be considered carefully for each project and that superficial or non-committal participation can be more damaging to a project or a community, than a complete absence of participation.

10.2.5 The productivity of participation

When carefully approached and thoughtfully executed, high-level participation can be productive (as suggested by Krueger *et al.*, 2012 also), both for the environment and for the community. Benefits that have been specifically highlighted by this study include a heightened group understanding of an issue or process through co-produced knowledge, social learning and effective focusing of research efforts. When beginning a participatory process, practitioners should consider the benefits they wish to achieve from the approach, but should also be open to unexpected developments and benefits, and be able to utilise these for the good of the environment and the community.

10.2.6 Bringing science and society together

Introducing traditional scientific tools and methods (e.g. hydraulic modelling) to a group with diverse interests and knowledges can be an effective way of integrating different types of knowledge. However, the approaches selected should be chosen with care and practitioners should aim to select methods which can expand the knowledge of all that are involved, but which are also accessible enough to the whole group so as not to intimidate any member. Failure to consider this aspect could lead to alienation of certain members, and fragmentation of the group. In this case, the impacts of the loss of group members (as discussed in Section 9.3.4) may be incurred.

10.2.7 Knowledge controversies: destructive or constructive?

The emotion that can be evoked through a knowledge controversy can be destructive to relationships if not dealt with appropriately. However, it can also be a constructive device, if harnessed, re-worked and channelled sensitively. Controversies, as presented in STS literature, are considered to be situations in which members of the public experience a 'crisis of confidence' (Callon, 1999) around the knowledge produced in science and technology, and their importance for new forms of knowledge generation has been widely publicised (e.g. Callon, 1999; Latour, 2003; Stengers, 2005; Whatmore, 2009; Lane *et al.*, 2011). This study, however, considers the role of situations which have not resulted in such an overt crisis of confidence, or threat to public wellbeing, but which are sufficiently provocative of public response to facilitate action within a group. The Ebchester Study demonstrated these 'situations of importance' can also be highly constructive environments, but that the longevity of a concerned group is dependent upon their

presence and, once removed, the dynamics of the group may become unstable and subject to change (this may be applicable also to controversy situations, but it is less likely that deep-lying controversies would be so easily 'fixed').

This research has demonstrated that the presence of a knowledge controversy or a situation of importance is effective in unifying and motivating a group to the point of action, and beyond, but that long-term commitment may be jeopardised in less contentious situations. This distinction should be considered at the outset of any participatory process.

Recommendation	Details	Relevant thesis section
<i>Cognitive</i>		
Determine whether there is a controversy or situation of interest	The nature and degree of public interest may be affected by the situation context. Consider whether a group's longevity would be affected by a change in the controversy or situation of interest	Sections 10.2.4 and 10.2.7
Differentiate between experiential and co-produced knowledge	It is easy for sceptics to dismiss experiential knowledge and claim that it cannot be validated. Ensure that all knowledge (experiential and scientific) used in decision-making has faced a process of debate and deliberation in order to present more robust outcomes and minimise uncertainty	Sections 9.2.2.2 and 10.2.3
Invite and encourage participants to debate scientific and experiential knowledge through an iterative process	Robust and context-specific knowledge can only be achieved through a process of deliberation and re-framing which is repeated until all members are satisfied with the quality of information. Therefore, it is important for all members to be open to questioning in order to validate process (scientific) knowledge for a specific area, or experiential knowledge in a specific field. Together, these two forms of deliberated knowledge will form a new, co-produced knowledge which is context specific and reliable. Do not be afraid to involve participants you think may question knowledge – they can be catalysts for discussion and assist in playing out uncertainties	Sections 9.2.2.2 and 9.4.1
<i>Approach/practice</i>		
Focus on the outcomes	Rather than trying to achieve prescribed processes or classifications/levels of participation, consider how the process adopted will help to deliver the social and environmental outcomes of a project. It also important to note that different approaches to participation may be appropriate for different project components	Sections 9.2.1 and 10.2.1

Careful selection of when to use participatory approaches is essential	Using participation for the wrong reasons (e.g. simply to be able to say that it has been done) can result in superficial results, participant apathy and weakened relationships between practitioners and members of the public. Conversely, allowing individuals or communities to voice concerns or discuss a system in an open and supportive environment can lead to pro-active groups and effective problem solving	Sections 4.3.3, 9.3 and 10.2.5
Use innovative engagement tools	The use of tools such as numerical modelling, mapping and field visits can engage group members and stimulate discussion. Such tools are effective for developing social learning as well as contributing to environmental deliverables	Sections 9.5 and 10.2.6
Use a holistic approach to river management and decision-making	In order to truly understand the impact of river management decisions, all aspects of the system must be accounted for. Therefore, an effective participatory process should be interdisciplinary and consider the physical, social, environmental, economic and logistical aspects of any decision	Section 10.1.1
Allow the participatory process to work for you	Involving members of the public and stakeholders in river management processes, from the outset, can be temporally and financially efficient. By allowing those with experiential knowledge to inform and shape research objectives, the most salient issues can be identified and addressed quickly. Participants can offer knowledge which would otherwise be costly to obtain – therefore, use the process as a resource	Sections 4.3.4, 9.4 and 10.1.2
Adopt participatory processes with a reflexive approach	While it is important to plan participatory processes carefully and to prepare for the difficulties they may present, it is imperative that practitioners are equipped and willing to accommodate unexpected problems. Do not be disheartened by unexpected outcomes – they will often offer new insights. A lack of reflexivity can result in superficial outcomes, collapse of the project, or the loss of trust from participants	Section 10.1.2
Avoid labelling group members according to their expertise	The process of knowledge co-production in this study has shown the knowledge and understanding of the problem, as possessed by <i>all</i> members to grow through the process. Therefore, ‘expertise’ can be considered as a process rather than a status, and the classification of an ‘expert’ should only be applied once the knowledge production process is complete. This will assist in reducing power barriers and allow all members to offer and receive information without judgement	Section 2.4.3
Look beyond the individual project	Where possible, aim to maintain contact and the process of learning after the more tangible goals of the project have been realised. This will allow the group as a whole to experience the benefits of social learning. Furthermore, practitioners should use the process to allow themselves, as well as the other participants, to learn	Section 9.4.2

Logistical		
Think carefully about the pre-existing dynamics between group members	The members which make up a research group may bring with them existing dynamics and power roles. It is important that these are understood (and where appropriate, managed) from the outset in order to avoid frictions, complications or unsettlement within the group	Section 9.3.2.1
Communicate regularly	Communicate regularly with participants (even if there is little to report) to ensure engagement is maintained and to identify any issues or potential loss of group members in time to address them, if appropriate. Give thought to the communication methods used, so that no participant is allowed to feel sidelined or disconnected	Section 9.3.2
Involve as many people as possible	The main knowledge production group may not include a great number of members. However, try to keep the wider community (whether residential, managerial, research) involved by offering information and progress to them, as well as within the competence group. This may facilitate a positive reception of a project, or help contribute to promotion, implementation and monitoring	Section 10.1.2 (Q3)
Consider scale when selecting participatory approach	Higher levels of participation are generally most effective at local scales (although not exclusively). If a number of small scale projects are to be combined, consider the impacts of 'scaling up' on the overall outcome and consider having a number of levels of 'validation' involving knowledge from a range of scales, for various steps of the process	Sections 9.2.2.1 and 10.2.2

Table 10.1 Recommendations for participation practice, derived from the findings of this study

10.3 Further avenues for research raised through this study

While addressing the research questions set out in Section 2.6, and the issues highlighted in Section 9.1, the findings of this research have, as with all knowledge development processes, given rise to further questions. Building on the findings presented here, a number of issues require consideration in further detail. These are discussed below.

10.3.1 Broader application to river sciences

The focus of the Ebchester Weir project (the degrading weir) was on an issue which was of particular concern for a number of citizens within the Derwent catchment and was a visual, present and growing issue. These aspects made the issue, in this case, highly topical and created much dialogue within the group, leading to a constructive outcome in terms of knowledge production because the group were able to report clear observations of changes within the channel over the years. Furthermore, the modelling component of the project served to

stimulate conversation and debate over scientific knowledge but this project cannot conclude on the effectiveness of other forms of river research tools (e.g. water quality analysis or habitat surveys) in inciting such deliberation. Therefore, whether the participatory approach taken would be as successful for alternative issues is unknown. For example, the issue of water quality as a result of metal contaminants was present for a number of residents in the Derwent catchment. For a less 'tangible' issue, such as heavy metal contamination, it is unclear how successful a deliberative process would be and it is possible that there would be even greater resistance of experiential knowledge by certified experts for such a topic. Consequently, further investigation would be necessary to determine the breadth of application for the references made here to participation in river research and management modelling. An investigation similar to that presented in this thesis is recommended to establish the applicability of the approach described in this study to wider fluvial aspects. However, based on previously documented examples of the success of a high-level participatory approach in various river studies (e.g. Cockerill *et al.*, 2006; Lane *et al.*, 2011; Bracken *et al.*, 2012), broader environmental management (e.g. Giordano and Liersch, 2012; Krueger *et al.*, 2012) and beyond (e.g. Wynne, 1987, 1989; Rowe and Frewer, 2005; von Korff *et al.*, 2010), there is reason to believe that such an approach offers significant potential in developing holistic understandings of a number of fluvial and riparian issues. What may be of benefit to the field is an analysis of the cumulative message offered by these individual studies which synthesis the conclusions and applies them to the broader topic of river management, offering a 'portfolio' of suggestions for success, as well as precautionary principles, for higher-level participation in river research and management.

10.3.2 Definition of an optimum scale for higher-level participation

The results of the study have raised the question of whether high-level participation (e.g. delegated power or citizen control: Arnstein, 1969) and the process of knowledge co-production could be successfully scaled up for catchment-wide application. It would be useful therefore, to river managers specifically, if the existence of an optimum or maximum scale could be determined. As discussed in Section 3.4.3.1, the optimum size for a productive focus group is six to ten people. If the participatory approach used in this study was to be applied to a project of scale greater than a reach (c.100m), it is unlikely that sufficient expertise could be gathered from such few members. Therefore, an investigation into the capability of a range of participatory approaches (e.g. public meetings; surveys; online portals and data collection; participatory GIS) in accounting for experiential knowledge at a range of scales would be beneficial. Building on the methodology of the current study, one approach to 'scaling-up' may involve analysis of the feasibility of combining co-produced knowledges from a number of competence groups within a

sub-catchment (and considering how these reach-scale combined knowledges would themselves be questioned and re-framed to address the issue at the sub-catchment scale).

10.3.3 A revised classification for knowledge production processes?

This study has recommended caution in attempting to categorically classify knowledge production processes according to some of the modes described and used for discussion in this thesis (e.g. Mode1/Mode2: Gibbons *et al.*, 1994, PDM/CKM: Callon, 1999). The issue raised concerning these approaches is that they are often based on little empirical evidence and are rather more theoretical. Certainly, they have not been developed around empirical cases of river research (much focus is placed on medical and energy research). Therefore, a 'portfolio' of case studies similar to this one would allow river researchers to begin to determine and characterise appropriate modes of knowledge production specific to river research or management, and would facilitate the selection process (of type of participatory process) for future participatory applications.

10.3.4 Reforming perspectives and valuing co-produced knowledge

Finally, high-level participation can never be fully effective for environmental change (and also perhaps in terms of social benefits) unless those who have the power to invest in the knowledge created learn to value the process and the products. This requires changing the perspectives of many parties which have the power to accept and utilise the knowledge created through deliberation of a diverse group of experts. This recommendation does not refer to an individual or a specific aspect of further research, but points to the championing of the approach by its early advocates. This process may be lengthy and troublesome, but there is evidence that it has begun, and the development of studies such as this should aim to further strengthen the cause.

10.4 Final summary

This study has demonstrated the benefits of a participatory process, reinforcing the abundant literature already calling for the adoption of high-level participatory and interdisciplinary approaches in river research and management. However, it has also shed light on some of the assumptions that may lead to difficulty in achieving the benefits of participation, if the process is not planned and executed thoughtfully and reflexively. A distinction has been drawn between the *right* and the *desire* to participate and the implications of failing to differentiate between the two. A disconnect between knowledge production theory and practice were identified and the reasons for this were explored. However, the final conclusion of the study is that PAR and the sensitive

use of controversies can be highly productive when approached practically, and can be inspirational when creative thinking and adaptation are fostered.

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Appendix A: Benefits of a participatory approach to river management

Main group to benefit in each way is highlighted, however for many of the examples, many groups/classifications may benefit. P = Participants; E = Environment; M = Managers; D = Decision-making

Benefit	Source	Normative or pragmatic?	Primary bene-ficiary
Prevents marginalisation of those on the periphery of the decision-making context or society	O'Riordan, 1971; Martin and Sherrington, 1997; House, 1999; Junker <i>et al.</i> , 2007; Pickup <i>et al.</i> , 2004; Reed 2008; Henriksen <i>et al.</i> , 2009	Normative	P
Empowerment of participants, allowing them to 'find their voice'	Greenwood <i>et al.</i> , 1993; Okali <i>et al.</i> , 1994; Macnaghten and Jacobs, 1997; Wallerstein, 1999; Pets, 2007; Reed, 2008	Normative	P
Promotion of social learning	Pahl-Wostl, 2002; Craps <i>et al.</i> , 2003; Blackstock <i>et al.</i> , 2007; Petts, 2007; Junker <i>et al.</i> , 2007; Reed, 2008; Henriksen <i>et al.</i> , 2009	Normative/ Pragmatic	P
Increased trust between participants	Forester, 1999; Leeuwis and Pyburn, 2002; Pahl-Wostl and Hare, 2004; Stringer <i>et al.</i> , 2006; Reed , 2008	Normative/ Pragmatic	P
Participants learn to appreciate views and values of one another, potentially heal poor relationships	Forester, 1999; Clark, 2002; Leeuwis and Pyburn, 2002; Pahl-Wostl and Hare, 2004; Tippett <i>et al.</i> , 2005; Stringer <i>et al.</i> , 2006; Harris <i>et al.</i> , 2012; Cheng and Mattor, 2006; Hayward <i>et al.</i> , 2007; Stewart and Sinclair, 2007; Reed , 2008; Emery <i>et al.</i> , 2013	Normative/ Pragmatic	P
Social relevance produces a sense of ownership and long term support/enthusiasm /implementation of decisions	Susskind and Cruikshank, 1987; Martin and Sherrington, 1997; Junker <i>et al.</i> , 2007; Wissmar and Beschta, 1998; Tunstall <i>et al.</i> , 2000; Dukes and Firehock, 2001; McDonald <i>et al.</i> , 2004; Richards <i>et al.</i> , 2004; Walker, 2004; Petts, 2007; Reed, 2007; Reed, 2008; Reed and Dougill, 2010	Normative/ Pragmatic	P
Identify public concerns and values. Decisions are made relative to the community that defines, and re-defines the	Creighton, 1981; Bauer and Randolph, 1999; Eden <i>et al.</i> , 2000; McDonald <i>et al.</i> , 2004; Stirling, 2006; Junker <i>et al.</i> , 2007	Normative/ Pragmatic	P

river/place/system

Participants learn how to solve shared problems in a manner responsive to factual correctness and normative consent	Webler, <i>et al.</i> , 1995; Petts, 2007	Normative/ Pragmatic	P
Participants are allowed to become aware of, and identify with their environment	Creighton, 1981; Weichhart, 1990; Fordham <i>et al.</i> , 1991; Volker, 1997; Bauer and Randolph, 1999; House, 1999; Buckecker <i>et al.</i> , 2003; Stirling, 2006; Junker <i>et al.</i> , 2007	Normative/ Pragmatic	P
Participants have a role in quality control of the produced operational knowledge	Henriksen <i>et al.</i> , 2009	Normative	P
<i>Early</i> participation helps include a variety of ideas and perspectives in project design (and therefore more likely to meet local needs) (and reduce conflict: Walker, 2004)	Dougill <i>et al.</i> , 2006; Reed, 2008	Pragmatic	M
Can anticipate and ameliorate unexpected negative outcomes before they occur	Fischer, 2000; Beierle, 2002; Koontz and Thomas, 2006; Newig, 2007; Reed, 2008; Fritsch and Newig, 2012	Pragmatic	M
Ownership and a sense of responsibility for the work could lead to reduced implementation costs	Reed, 2008	Pragmatic	M
Encourages people to learn actively and think systematically in complex situations involving controversy	Walker <i>et al.</i> , 2006; Petts, 2007	Normative/ pragmatic	M
May increase support for decisions and for possible controversial policy proposals	Henriksen <i>et al.</i> , 2009; Carr <i>et al.</i> , 2012	Pragmatic	M
Helps participants to understand the difficulties in management and/or decision-making processes	Walker 2004	Normative	M
Environmental decisions perceived as holistic and fair, accounting for diversity of values and needs	Richards <i>et al.</i> , 2004; Reed, 2008	Normative	M
Enables interventions and technologies to be better adapted	Reed, 2008; Tippett <i>et al.</i> , 2005 - helps people to adapt to changing	Pragmatic	E

to local socio-cultural and environmental conditions	circumstances			
More robust research by providing higher quality inputs and a reflexive approach	Hansen, 1994; Clark, 2002; McDonald <i>et al.</i> , 2004; Walker, 2004; Reed <i>et al.</i> , 2006, 2008; Reed, 2008;	Pragmatic	E	
Expert science and analysis needs to be quality assured through lay input and local knowledge can help to validate process assumptions	Funtowicz and Ravetz, 1991; Renn <i>et al.</i> , 1995; Welp, 2001; Bowden <i>et al.</i> , 2004; Petts, 2007	Pragmatic	E	
Improvement in quality and effectiveness of policy proposals	Pelletier <i>et al.</i> , 1999; Henriksen <i>et al.</i> , 2009	Pragmatic	E	
The views of the public are rarely the same as those of the interest groups or local councillors who represent them at the formal consultation level, therefore a more diverse view of issues can be addressed	House and Sangster, 1991; House, 1999; Walker, 2004	Pragmatic	E	
Contribute to the definition and accreditation of scientific knowledge	Irwin and Wynne, 1996; Bucchi, 1998; Bucchi and Neresini, 2008	Pragmatic	E	
Increase in public trust in decisions	Beierle, 2000; Beierle and Cayford, 2002; Schneider <i>et al.</i> , 2003; Richards <i>et al.</i> , 2004; Junker <i>et al.</i> , 2007; Reed, 2008; Henriksen <i>et al.</i> , 2009; Carr <i>et al.</i> , 2012	Normative	D	
Allows a decision-making process which recognises the complexity of human-environment interactions	Richards <i>et al.</i> , 2004; Reed, 2008; Harris <i>et al.</i> , 2012	Normative/ pragmatic	D	
Enhances the capacity of decisions and measures to meet local needs and priorities	Martin and Sherington, 1997; Reed, 2007; Reed, 2008; Reed and Dougill, submitted (in Reed 2008)	Normative/ pragmatic	D	
Can lead to better quality decisions based on more complete information	Coenen <i>et al.</i> , 1998; Fischer, 2000; Gee <i>et al.</i> , 2001; Beierle, 2002; Mostert, 2003; Walker 2004; Junker <i>et al.</i> , 2007; Koontz and Thomas, 2006; Newig, 2007; Reed, 2008; Fritsch and Newig in press (in Reed 2008); Harris <i>et al.</i> , 2012;	Pragmatic	D	
Adaptive management allows the process to be open to re-specification of the target	Clark, 2002	Pragmatic	D	

Appendix B: Suggested limitations of, and barriers to, successful participation, as highlighted in relevant literature sources

Limitation	Source	Note
Participation does not take place in a power vacuum (power relations are still in force)	Cooke and Kothari, 2001; Blaikie, 2006; Reed, 2008	Power related
Empowerment of previously marginalised groups may have unexpected and potentially negative interactions with existing power structures	Kothari, 2001; Reed, 2008;	Power related
May reinforce existing privileges for some	Nelson and Wright, 1995; Reed, 2008	Power related
Group dynamics may cause some minority perspectives to be overlooked/ignored/missed ('Dysfunctional consensus' – Cooke, 2001)	Cooke 2001 p19; Nelson and Wright, 1995; Reed, 2008;	Power related
Consultation fatigue (particularly if results are not delivered or participants continue to have little influence)	Handley <i>et al.</i> , 1998; Duane, 1999; Cosgrove <i>et al.</i> , 2000; Wondolleck and Yaffee, 2000; Burton <i>et al.</i> , 2004; Reed, 2008	
Friction, consultation fatigue and indecisiveness may result if there are certain cases which are non-negotiable with those who have the overriding power	Broad <i>et al.</i> , 2007 (for a case study); Reed, 2008	Power related
Where there are still power imbalances and some non-negotiable aspects, can lead to reduced engagement	Broad <i>et al.</i> , 2007 (for a case study); Reed, 2008	Power related
The argument that SHs don't have the expertise, knowledge (or status?) to participate in technical conversations	Vining, 1993; Eden and Tunstall, 2006; Fischer and Young, 2007; Junker <i>et al.</i> , 2007; Reed, 2008	
Participation can be time consuming, delay end results and cause the process to be more lengthy	Clark, 2002; Mostert, 2003; Walker, 2004; Junker <i>et al.</i> , 2007; Carr <i>et al.</i> , 2012	As much UK funding is short-term and piecemeal, it does not lend itself to depth of understanding from diverse

		perspectives and iterative approaches (Eden and Tunstall, 2006)
Practitioners sometimes believe that Involvement of community goals may cause deviation from what 'the science' suggests is the best approach and this can cause the project to become unsustainable, if the project is based on a model of system response	House and Fordham, 1997; Mason, 1997; Skollerhorn, 1998; Mostert, 2003; McDonald <i>et al.</i> , 2004; Junker <i>et al.</i> , 2007	Newson suggests that deviating from 'normal' path can be a good thing
Processes/approaches developed locally are not always transferable	Petts 2007;	
Experts may find the process uncomfortable and struggle to communicate on a suitable level with non-expert members of the group	Petts, 2007 pg 308; Cook <i>et al.</i> , 2011	
River managers tend to focus on the risks rather than the benefits of public involvement	Junker <i>et al.</i> , 2007	
Friction/controversy occurring between groups with contrasting interests	Eden <i>et al.</i> , 2000; Eden and Tunstall, 2006	Eden and Tunstall, 2006, also suggest this can be productive if channelled effectively.
Lack of interests from potential participants	Bucheker <i>et al.</i> , 2003; Junker <i>et al.</i> , 2007;	
Financial responsibility and decision-making responsibility may be shifted away from government and transferred to participants	Carr <i>et al.</i> , 2012	
Inappropriate or insufficient management of expectations for all parties	Rhoades, 1998; Hansen and Maenpaa, 2007	
A widening of the gap between the public, and management organisations – as people develop a better understanding of the science behind decisions, they may be less trusting of the decisions made	Petts, 2007	It has been widely argued that this is a right of the public (see Section 2.3)

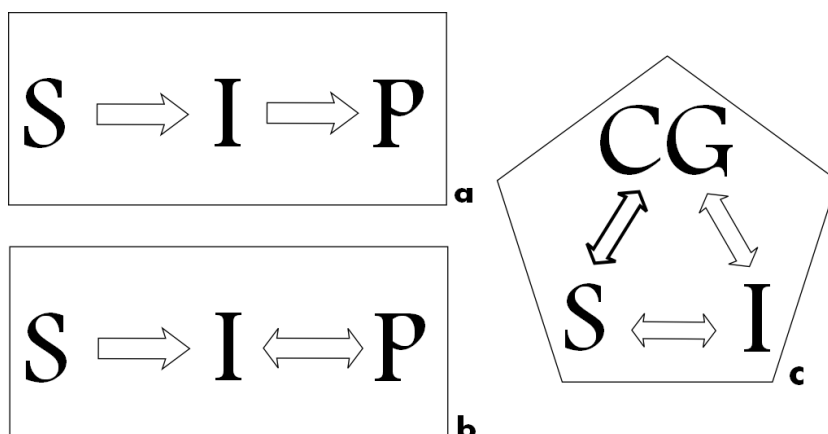
Appendix C: Interview questions used for all participants of Organisational Review

1. What is the aim of your river restoration project?
2. What approach have you taken to river restoration – i.e. methods – what have you done/are you planning to do?
3. What approach have you taken to public participation?

If the interviewee offered a brief answer, the following questions were used to encourage elaboration:

- At what point did you involve participants?
- Which methods have you used?
- How regularly do you communicate?
- How much influence do participants have over decisions being made?
- Which participants did you use? / how were they selected?
- Who manages/oversees/conducts the participation?
- Why did you choose that specific approach to participation? – was it specific to the problem in hand or is it a standard, pre-determined approach?

4. What constraints are placed on you and your organisation in terms of participation?
5. Do you feel that your approach to participation has enhanced the project/outcome? How/why?
6. What was your aim for the participation aspect of the project?
7. Which parts do you feel have/have not worked well?
8. Can you assign your approach one of these models: (*Callon models were described in turn before interviewee was asked to assign their approach*)



9. If you were able to, would you change/develop your approach to participation? In what way?

Appendix D: Information leaflet provided to interested parties during establishment of competence group

How can I get involved?

We are looking to establish a group of interested individuals (a competency group) who can work with us to identify the issues that exist on the River Derwent and determine what can feasibly be addressed. Those involved would be asked to attend a number of sessions (around 6) across the period of roughly one year. In these sessions we will discuss what concerns people have for the physical, biological and chemical nature of the river. We will then try to find some solutions for one or more of these issues, using scientific methods, combined with your experience and knowledge to assess how suggested restoration measures may help (or not help). It is proposed that the sessions will address these topics (this is a provisional list and is likely to change in response to the direction each meeting moves):

- Frame the problem and identify issues within the catchment
- Development and demonstration of a numerical model – informed by both scientific and experiential knowledge
- Use of the model to explore management options
- Revised scenarios
- Choice of preferred solutions

What we can offer you:

- A chance to be part of a community group
- The chance to voice your opinions on the state of the river
- An opportunity to develop scientific tools to explore the problems and possible solutions for the river
- An opportunity to contribute to a project which will examine the merits of public involvement in what are traditionally 'scientific' practices.

We cannot promise that the process will improve the river environment – this is an experiment to determine whether this type of involvement can be beneficial. Therefore, we may find that this approach is not effective, but valuable lessons will be learned about how river restoration can be addressed.

Public involvement in river restoration: what is it all about?



In conjunction with

 Durham University

Carly Maynard
 Department of Geography
 Science Laboratories
 University of Durham
 South Road
 Durham
 DH1 3LE

c.m.maynard@durham.ac.uk

If you think this project is something you can contribute to (remember - no scientific knowledge or training is required) and would like to be involved in the competency groups, please contact Carly Maynard to discuss the process further.

Public involvement in river restoration — what we are trying to do, and why we need you

You are receiving this leaflet because you have expressed an interest in our river restoration and public participation project. We hope this leaflet will provide you with more information and answer some of the questions you may have. If you have any queries after reading this, or would be interested in being part of our group, please do not hesitate to contact us, using the information provided at the end.

What is river restoration?

The word restoration is used in a number of ways, ranging from the changing of a river environment to a pre-disturbance state through hard engineering, through habitat rehabilitation, to the conservation of an environment that currently exists. The word restoration is often used as an umbrella term to describe processes that more closely resemble recovery, rehabilitation or enhancement. It is important to clarify the definition of restoration for a certain project, before the project begins, to make sure that the expectations for the project from each party are based on the same understanding. It is also important in providing a consistent and transparent base from which we can work and make catchment management decisions. For the purposes of this project, restoration can be defined as:

“measures implemented to mitigate or compensate directly for damage caused by a recent or current development”

This definition allows us to address any one of a number of different issues within the channel, including the exploration of ‘soft’ approaches, such as habitat improvement. This flexibility results in an approach which can focus upon the goals that each participant has for the river.

Why do we need it?

Many of the UK’s rivers have been heavily modified in recent decades, for reasons such as flood alleviation, management of water resources or land drainage. The River Derwent is no exception and it has been changed in a number of ways, including channelization, impoundment and channel modifications such as fish passes, weirs and energy generation works.



As a result of channel modifications, the nature of the channel changes, and finding a ‘natural’ channel in the current environment is increasingly difficult. With increasing pressure from legislation such as the EU Water Framework Directive and the EC Habitats Directive, there is a requirement to help our rivers return to a more natural state. The alterations that are made to the flow and form of the river cause changes in the dynamics of the whole river system and can change the way the river looks, as well as the habitat available for animals and plants. Restoration activities are designed to help restore river systems to a condition that more closely resembles their natural state.

What is the aim of the project?

This project aims to investigate the impact of including members of the public, and the people who use the river on a day to day basis, in making important decisions about how the river should be managed, starting with the identification of the major issues in the catchment. We believe that by working together to identify problems, and investigate potential solutions, we can make more efficient and effective decisions about how a river can be improved. We hope that this will lead to a management strategy that benefits everyone involved, as well the ecology of the channel.

What can public involvement do to improve the process?

By involving all interested parties, wholly and from the outset, the issues that are most important, and that can be feasibly investigated, will be identified at an earlier stage.

Once the issues within the catchment have been identified, a number of potential solutions can be explored through group discussion. Involving those who have experiential knowledge of the river will help us to determine what the specific outcome of any changes might be and provide insight into details such as the optimum location for management measures and local implications. It is hoped that the impact of potential solutions can be modelled using numerical models and that all participants can be involved in the modelling process. This will allow us to determine whether model results are acceptable and provide a true picture of what we can expect of the catchment. Once we know that the models are performing correctly, we can use them to assess different management options for the river.



After possible solutions have been explored, we can, as a group, decide upon the optimum approach to tackling issues.

No scientific expertise is necessary for you to make a contribution to the process—the aim is to incorporate all types of knowledge into a decision making tool.

Appendix E: Advertisements used for drop-in session in Derwent catchment

Your River – Your Voice

Are you interested in the state of your river, for fishing; for recreation; for ecology; for flood protection?

We are a team of researchers at Durham University who are interested in developing river restoration options for the River Derwent. We want to investigate management options that have been established and developed by the whole community.

If you have concerns about the river or are interested in how it is managed, we would like to hear from you. We are holding a drop-in meeting where we hope to gather your views around issues in the River Derwent and its catchment.

When: Thursday 25th November, 7-9pm (with a summary session from 8.30pm)

Where: Ebchester Community Centre, Shaw Lane, Ebchester

Contact: Carly Maynard: c.m.maynard@durham.ac.uk Phone: 07510661028

Please feel free to get in touch if you have any further questions or would like more information.

Please let us know if you would like to come along so that we can arrange refreshments
Department of Geography, Science Site, University of Durham, South Road, Durham.
DH1 3LE



Appendix F: Derwent catchment environmental designations

Designation	Area within Derwent catchment
<p>SPA (Special protection area) Part of the Natura 2000 network designated under the European Habitats and Birds Directive. Provides protection to birds and their nests, eggs and habitats.</p>	<p>Covering large areas of the catchment to the south of Derwent Reservoir and as far east as Crooked Oak</p>
<p>SAC (Special area of conservation) Part of the Natura 2000 network designated under the European Habitats and Birds Directive. Contributes to the maintenance and restoration of habitats and species.</p>	<p>Covering large areas of the catchment to the south of Derwent Reservoir and as far east as Crooked Oak</p>
<p>SSSI (Site of special scientific interest) A prerequisite to designation as SAC or SPA. This is a national level designation overseen by Natural England. A SSSI can be an area of land that is of special interest by reason of its flora, fauna or geological or physiographical features (as defined by Natural England).</p>	<p>Covering small parts of the catchment near Crooked Oak and further downstream near Rowlands Gill</p>
<p>SNCI (Site of Nature Conservation Interest/ Importance) A county scale designation. Overseen by the County Wildlife Trust and provides protection to wildlife and habitats.</p>	<p>Covering small parts of the catchment near Crooked Oak, muggleswick and Ebchester</p>
<p>AONB (Area of outstanding natural beauty) Managed by local authorities, organisations and community groups, the aim of an AONB is to draw special attention to an area because of its flora, fauna, historical/cultural associations or scenic views.</p>	<p>Covering all of the catchment upstream of Allensford</p>


Appendix G: Management plans and approaches encompassing or affecting the Derwent catchment

Strategy	Purpose
Tyne Catchment Plan, 2012	Developed by the Tyne Rivers Trust as part of the DEFRA 'pilot catchments' project. Designed to produce a plan to improve the catchment's water environment, the plan documents current and potential projects within the catchment and presents a way forward for 'joined up' management, all with a focus on thorough and meaningful <i>engagement</i> and the use of local knowledge.
River Basin Management Plan, Northumbria RB, 2009	Developed by the EA and DEFRA under the requirements of the WFD to coordinate and integrate the management efforts within the River Basin. Describes the characteristics of and pressures on the RB district. Outlines plans for action and implementation, leading up to the end of the first cycle in 2015, to help protect, improve and develop a sustainable water environment.
Derwent Water Order (1957)	Designed to manage the water impounded by and released from the River Derwent by NWL. Regulation of the River Derwent began in 1966. The compensation flow rate is set at a total rate of 9533 Ml/y (23.85 Ml/d and a spate allowance of 827 Ml in one year). It is permissible, by law, to vary the volumes of water released, provided that the annual minimum volume is released.
Tyne CAMS (Catchment Abstraction Management Strategy, 2005)	Used to assess the current stresses on water resources and develop sustainable licensing strategies to balance needs of the ecology water users. Revised release regimes from the reservoir must be able to meet the abstraction requirements of current licence holders. CAMS also governs how Northumbrian Water Ltd can abstract water from the River Derwent and Derwent Reservoir, in line with the 1957 Derwent Water Order.
CFMP (Catchment Flood Management Plan)	Outlines areas at risk from flooding, types of flood risk and management practices in place or proposed to prevent and/or accommodate flooding in the Derwent Catchment. Any increases in flow under new flow regimes must not increase the chances of flooding, as outlined in the CFMP.
Tyne Salmon Action Plan	Includes area of River Derwent. There are no salmon currently in the River Derwent, however, should salmon be able to access the Derwent, future Salmon Action Plans would include assessment of stocks and management practices for salmon in the River Derwent.
Summary of significant water management issues (2007): Northumbria River basin District (part of the EU WFD)	Highlights issues such as physical modification and minewater pollution. Definition of these issues is used to set environmental objectives for each water body within each EU WFD River Basin District. Under the EU WFD these objectives must be met unless significant reason can be given to justify their failure. The aim of this is to ensure that water bodies are brought to a good standard across Europe over the next 10-20 years.
NWL Water Resources Management Plan, 2009	Outlines how NWL intend to balance supply and demand over the next 25 years
Asset Management Plans (AMPs)	Outline the management of infrastructure and other assets maintained by water companies


Appendix H: Preliminary model results summary for use in deliberation with competence group members

Ebchester Weir River Derwent

Potential Impacts of Weir Restoration



Carly Maynard, March 2013

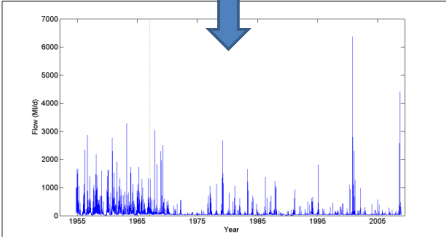


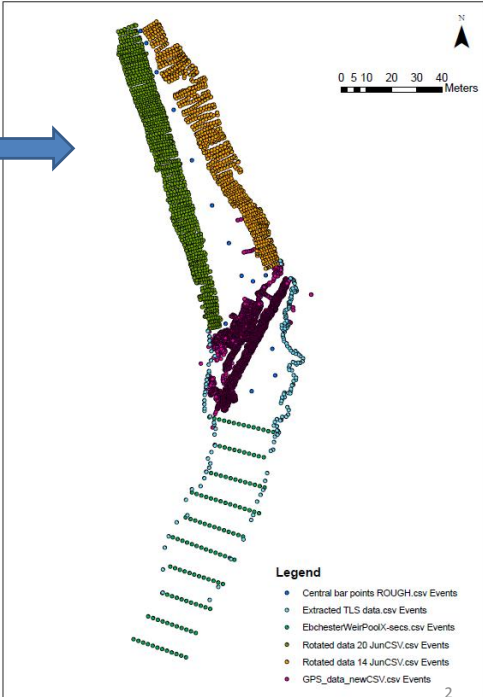
1

Data collection to use in numerical model

Lots of methods were used to collect information about the shape of the river bed. These included GPS, scanning equipment and a laser surveyor, as well as cross sections collected by the Tyne Rivers Trust and Sea Scouts. The different colours show different data collection methods

Long term flow data were also needed to tell the model what kind of flows the river experienced

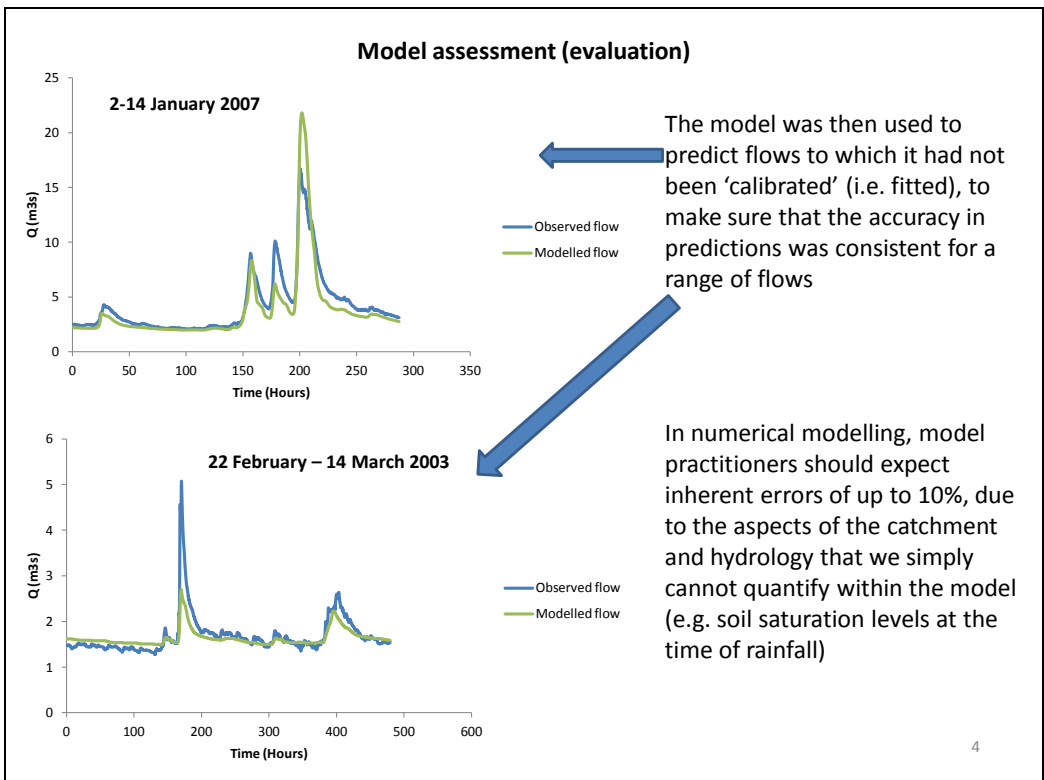
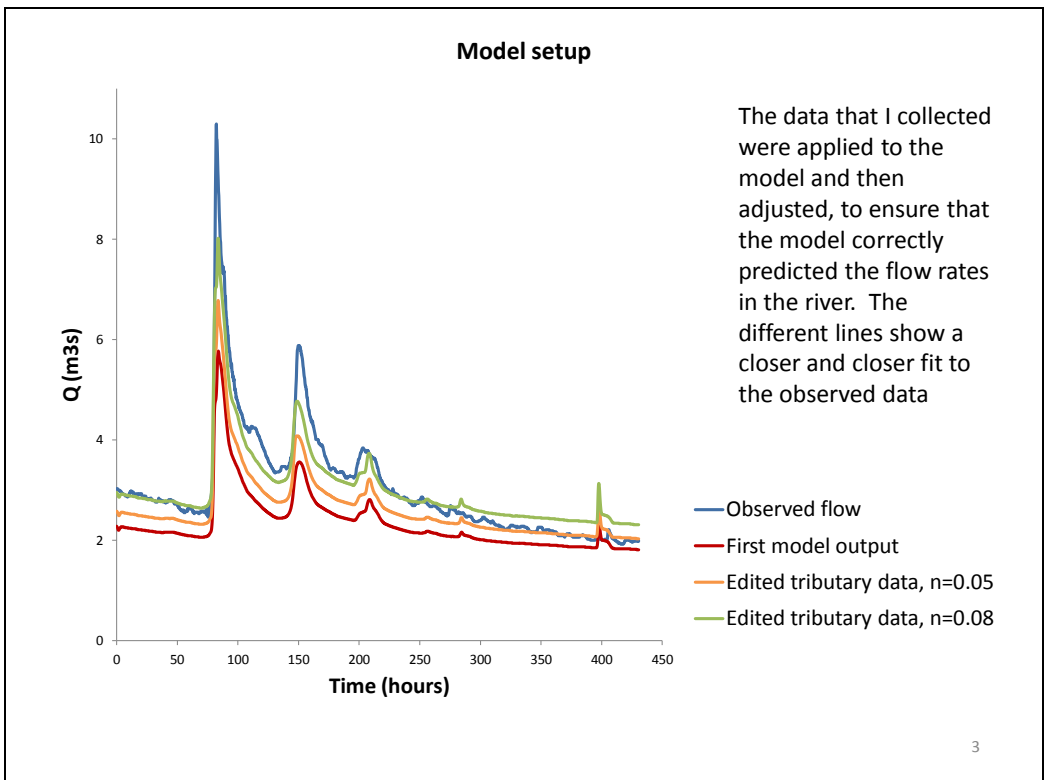




Legend

- Central bar points ROUGH.csv Events
- Extracted TLS data.csv Events
- EbchesterWeirPoolX-secs.csv Events
- Rotated data 20 JunCSV.csv Events
- Rotated data 14 JunCSV.csv Events
- GPS_data_newCSV.csv Events

2

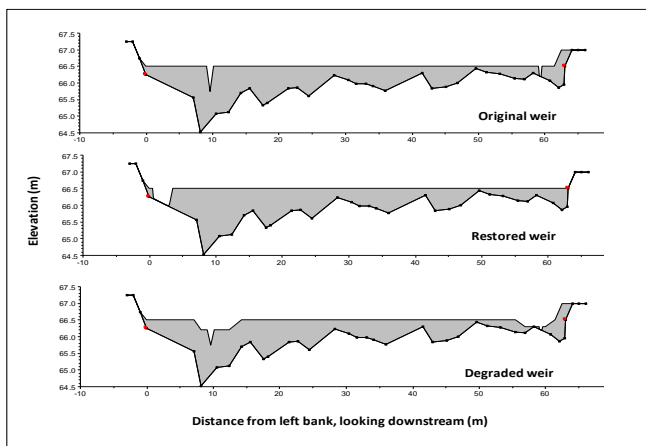


Points of interest around weir restoration:

Under varying states of repair, how will the weir affect:

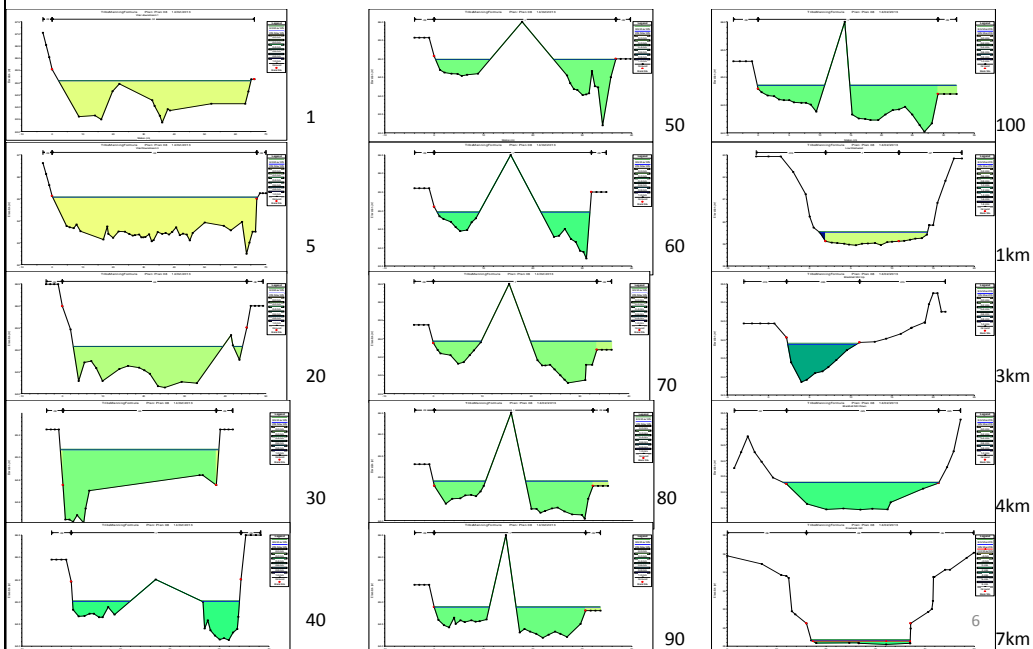
- 1. The impact of bar vegetation removal
- 2. Water level
- 3. Sediment dynamics (habitat)

These questions were investigated with weir profiles designed for the old weir (top picture), new weir (middle picture) and a hypothetically degraded weir (bottom picture, e.g. If the weir was not repaired and was left open to flood events)



5

These figures have been added to show how the model represents flow and velocity at each of the cross sections along the length of the bar, and how the shape of the channel changes. Velocity is represented by the strength of the colour green (dark green = fastest flow) and varies depending on the model conditions. The number to the right of each picture is the distance downstream of the weir in metres.



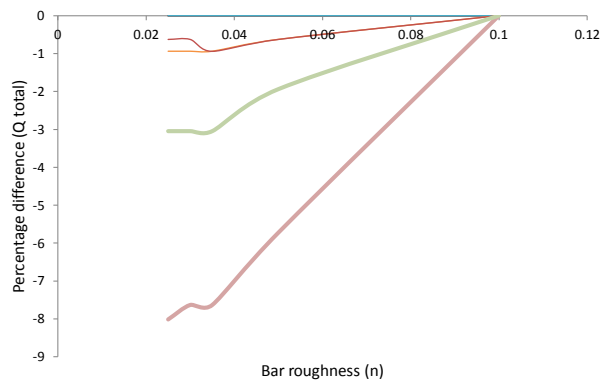
Q1. Removal of vegetation on bar

- Vegetation is represented in models as a roughness coefficient which is a numeric value assigned to certain areas of the river which determines how much friction the vegetation causes to the flow
- For the bar at Ebchester, the following scenarios were determined to be possible in various conditions:
 - Current state of dense, strong vegetation
 - Vegetation completely removed
 - Allowed to grow back for a short while
 - Allowed to grow back after 6-12 months
- **The roughness coefficient can be changed within the model to mimic these scenarios**

The shape of the weir had no impact on the main characteristics that were investigated (flow rate, water level, velocity), but changing the roughness value did have an impact (see page below)

7

Changing channel roughness has little impact on overall flow volume, where there is change, it is downstream of the bar at Ebchester



The purple line is the change in flow rate (as a percentage) downstream at Blackhall Mill, which shows there is a big difference in the predicted flow rate, based on the roughness of the bar at Ebchester

The green line shows the difference at Rowlands Gill, which is less, but still significant.

At other locations, which are near the bar at Ebchester (all of the other lines on the graph), there is little difference

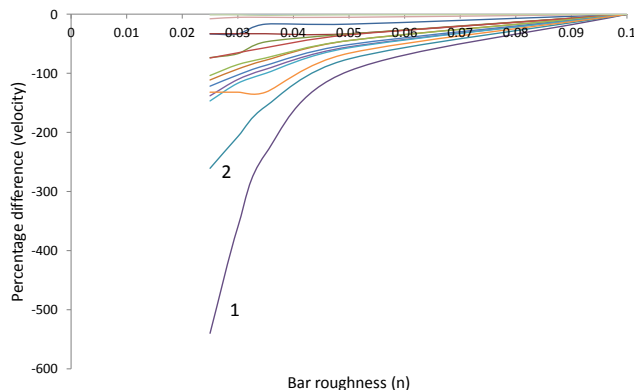
8

There is a varied response of velocity to change in roughness which is most pronounced around the area of the bar at Ebchester

The biggest difference to water velocity (speed) occurs at the most upstream point that the change in roughness is made (line 1)

The next biggest difference is 10m downstream of that point (line 2)

The least difference (flat lines at the top of the graph) are the areas that are over 500m away from the bar and the lines with a small amount of change are near the bar but downstream of where the change in roughness was made

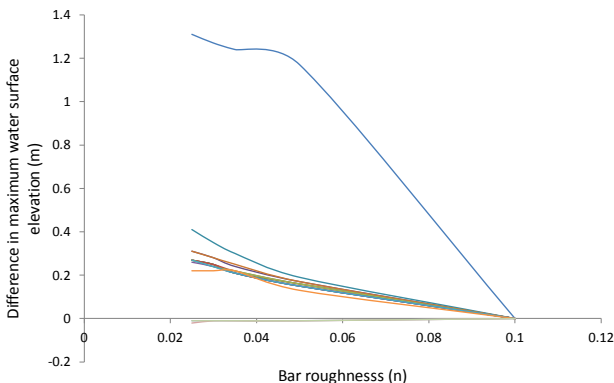


9

Change in water level varies between 0 and 130cm in response to roughness change. Changes are most pronounced around the area of the bar at Ebchester

The biggest change in water surface (shown as change in metres) occurs around half way down the length of the bar at Ebchester (blue line). i.e. The roughest channel causes the water level to be about 1m higher than the smoothest channel, according to the model.

This is probably due to a combination of a narrow part of the channel, and a high roughness causing water to 'back up' there



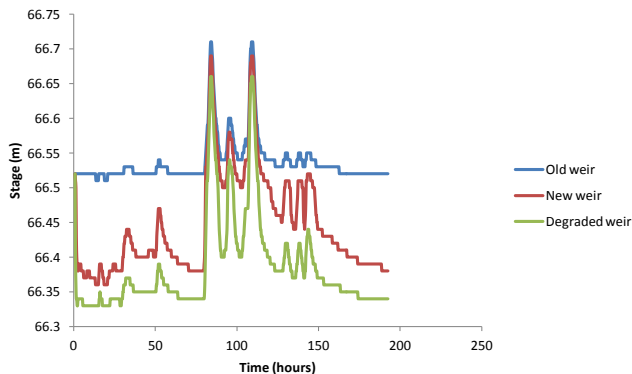
10

Q2. Water level behind weir

- Water level varies with different weir shapes
- The old weir caused the highest water level behind weir – this seems an unusual result – **is it what was observed?**
- No impact on overall flow (see Graph 2)
- No impact on flow OR water level downstream of weir

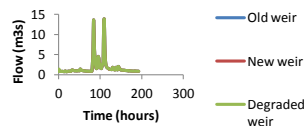
Graph 1

Water level behind weir



Graph 2

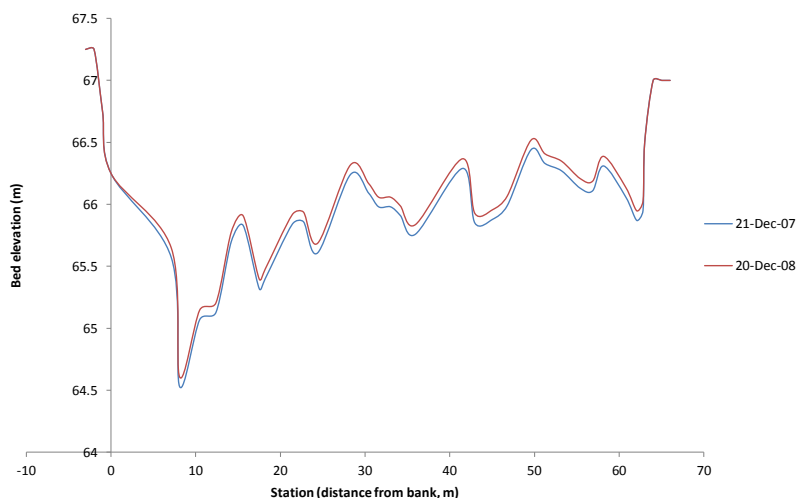
Flow behind weir



11

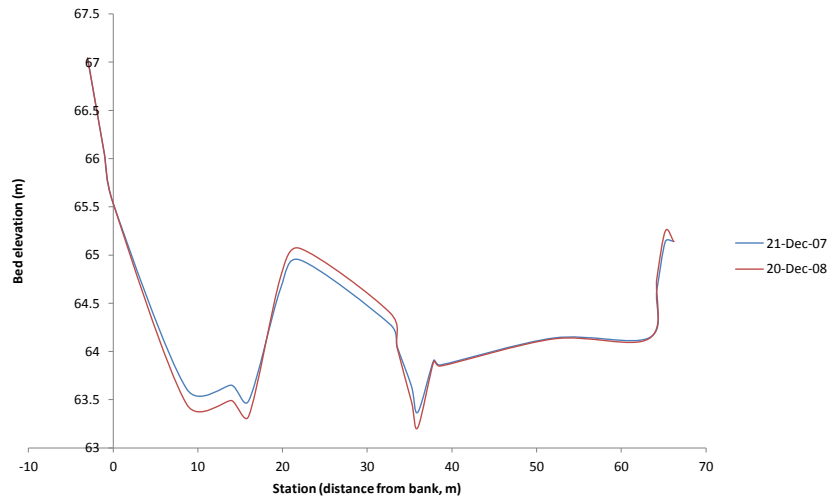
Q3. Changes to sediment

- I used the model to predict the change in bed sediment height one year after the weir was restored. The graph shows the cross section of the channel about 1 metre behind the weir. It can be seen that the model predicts there would be a small increase in the amount of sediment on the river bed – **is this what has been observed?**



12

This graph shows the cross section of the channel about 1 metre *downstream* of the weir. It can be seen that the model predicts there would be a small decrease in the amount of sediment on the river bed at the side furthest from the boathouse, a small increase in the middle and little change at the boathouse side – **is this what has been observed?**



13



If you would like any more information on how these results were obtained, what they mean, whether they look as you would expect, or what I am now doing to improve these results, please do get in touch:

c.m.maynard@durham.ac.uk

Please note that these results are not definitive and not final – they have simply been shared in case you are interested in the progress of the study

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