Nottingham Trent University

Natural Flood Management: Assessing the Barriers to Wider Implementation

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Dissemination Activities from this Project

Journal articles

Wells, J. and Labadz, J.C., 2017, Natural flood management: An integrated approach in a rural-urban catchment, Environmental Scientist "Living Labs", *Journal of the institution of Environmental Sciences.*

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Oral presentations

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2016, *Natural Flood Management in Southwell (Nottinghamshire) following an extreme rainfall event in July 2013*, 13th June 2016, British Hydrological Society Land use and hydrological extremes National meeting, Loughborough, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2016, *An Integrated Approach to Natural Flood Management: A Case Study of Southwell*, 15th June 2016, Trent rivers Trust making space for water in the Trent catchment, Newark, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017, Natural flood management in Southwell (Nottinghamshire, UK): an interdisciplinary approach in a rural-urban catchment, 24th April 2017, EGU General Assembly, Vienna, Austria.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017*, Natural Flood Management in Southwell, Nottinghamshire: intervention following an extreme event*, 26th September 2017, British Hydrological society Pennies Section Meeting: Natural Flood Management in Practice, Leeds, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017, *Natural flood management at Brackenhurst, Southwell: an integrated approach to working with natural processes***,** 6th December 2017, CIWEM Working With Natural Processes: The evidence base behind NFM, Leeds, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2018*, Natural flood management at Brackenhurst, Southwell: an integrated approach to working with natural processes,* 29th May 2018, Environment Agency Working With Natural Processes Roadshow, Keyworth, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2018*, Implications for natural flood management when upscaling to the wider catchment: findings from an interdisciplinary approach,* 7th June 2018, British Hydrological Society Peter Wolf symposium (Winner of Young Person's Prize for best oral presentation), Leeds, UK.

Poster presentations

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Other dissemination activities

Wells, J. and Labadz, J.C, 2016, "Flooding in Southwell"- Josh Wells- PhD Research, Southwell Community Resilience Handbook, Southwell Flood Forum.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017, An Integrated Approach to Natural Flood Management: Assessing the Barriers to Wider Implementation, February 2017, Oral presentation at the Southwell library (open to the public), Southwell, UK.

Wells, J., Labadz, J.C., Disney, A., 2017, *Case study 25. Natural flood management at Brackenhurst,* In Burgess-Gamble, L., Ngai, R., Wilkinson, M., Nisbet, T., Pontee, N., Harvey, R., Kipling, K., Addy, S., Rose, S., Maslen, S., Jay, H., Nicholson, N., Page, T., Jonczyk, J. and Quinn, P., 2017. *Working with natural processes- evidence directory*, Environment agency: Bristol.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017, Natural flood management at Brackenhurst, May 2017, Oral presentation to the Nottinghamshire FWAG group, Southwell, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2017, An Integrated Approach to Natural Flood Management: Assessing the Barriers to Wider Implementation, May 2017, Oral presentation to the Southwell Civic society, Southwell, UK.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2019, Natural flood management at Brackenhurst, Southwell: an integrated approach to working with natural processes, January 2019, Oral presentation to the Nottinghamshire Biodiversity Action Group Annual Forum, Southwell, UK.

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Abstract

Flood risk management (FRM) aims to reduce the likelihood and impacts of floods on society. Natural flood management (NFM) as a part of FRM aims to work with natural hydrological and morphological processes, features and characteristics to manage the sources and pathways of flood waters. It is increasingly proposed as a sustainable solution to manage recurrent flooding, both in the UK and other European countries, but significant barriers remain to its implementation. This study takes an interdisciplinary approach to identify and assess the barriers to uptake and implementation of NFM. The research has four key questions: 1) Can natural flood management impact on hydrograph characteristics? 2) To what extent is an at-risk community knowledgeable of NFM and how does this impact on attitudes? 3) What are the barriers to NFM uptake nationally and how do they apply in practice? 4) Can land manager exposure to NFM result in changes of knowledge, attitudes and behaviour?

Question 1 (impacts of NFM on the hydrograph), was investigated by constructing and monitoring an experimental NFM site in Southwell, UK. This included construction of earth bunds, a stream restoration reach and large woody debris on agricultural land upstream of the town. This study focused on the impacts of runoff storage within earth bunds. However, the impacts of the scheme as a whole are also discussed. Question 2 was answered using a questionnaire, sent to all households in the selected community. For question 3, semi-structured interviews were undertaken with land managers and individuals from professional FRM backgrounds in the UK. Data were analysed using qualitative methods, including thematic coding and categorisation. For question 4, land managers interviewed previously were invited to a demonstration of the site following the implementation of the experimental NFM. Attendees were subsequently interviewed to assess whether the site visit had an impact on their knowledge and attitudes.

Findings regarding question 1 (impacts on the hydrograph), show that at the slope scale a change in the peak stage relationship between the upstream and downstream loggers suggests that NFM intervention has had a positive impact in lowering peak stage during events. Moreover, storage within the bunds has reduced peak discharge during sampled events, with discharge shifting from the rising limb and peak of the hydrograph to the falling limb. Yet, the impacts on the hydrograph have been found to be limited during higher flow events, with the post NFM peak stage relationship curving towards the pre intervention linear trendline. When upscaling from the slope to the catchment scale, reductions in peak discharge became less important. Simulating the impact of a greater amount of storage at the catchment scale suggests that it could have a significant impact on discharge. For meaningful storage to be created, it is likely that more stakeholders will need to be involved across a larger catchment area. Therefore it is crucial that social barriers to uptake from multiple stakeholders are considered.

Results for question 2, (community knowledge and attitudes), show that the at-risk community's attitudes towards NFM were influenced by respondents' knowledge of NFM and their past experience of flooding. Residents who had experienced flooding in their homes exhibited less favourable attitudes towards NFM. Meanwhile, residents with a lack of knowledge of NFM were also more likely to be unfavourable towards it.

When investigating question 3, (barriers to NFM uptake), a total of 25 barriers were identified. Key ones are economic constraints for land managers, a current lack of scientific evidence to support NFM and lack of governance over long-term responsibility for NFM, which hinders future monitoring and maintenance. Practitioners were less likely to recognise other barriers noted by land managers, including cultural challenges, catchment planning concerns and lack of perceived control.

After the demonstration site visit for question 4, land managers' knowledge and attitude towards NFM had improved and some were considering NFM on their land. However, the lack of governance over the maintenance of NFM was still a significant barrier to uptake, as was the financial constraints of the farm. Policy is needed to guarantee the maintenance of NFM features in the future. Also, if public good is expected from private land, then financial incentive to land managers needs to be considered, to offset losses to the farm business.

The study has highlighted the importance of interdisciplinary research when insights into complex issues are sought. If NFM is to be implemented across wider catchment scales, the hydrological barriers need to be considered alongside the social barriers to uptake. It is vital for sustainability of future projects that policy makers and practitioners of FRM consider the constraints to NFM implementation identified across research disciplines.

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1. Introduction

1.1 Flooding and its wider context

Globally, flooding is the most frequent and most experienced form of natural disaster, affecting two billion people worldwide between 1998 and 2017 (UNISDR, 2017; Guha-Sapir, Hoyois and Below, 2013). One billion people live within floodplains and during the last century, nearly half of the people affected by natural disasters were affected by floods (Alfieri *et al.* 2017). Therefore, flooding is an issue which impacts upon societies and economies globally.

It is well established within the literature that climate change could increase the risk of flooding in many countries due to more frequent, intense and prolonged rainfall events (Alfieri *et al*. 2017; Dadson *et al.* 2017; Daigneault, Brown and Gawith, 2016; Driessen *et al.* 2016). It has been suggested that climate change could double to quadruple flood probabilities by 2080 with respect to those in 2000 (Thorne, 2014). When combined with the ever-growing desire to develop on the floodplain, flooding is becoming increasingly driven by human action (Hobeica and Santos, 2016). When human interaction is combined with the increasing threat of climate change, flood frequency and magnitudes may increase, causing greater economic and social losses. Effective flood risk management (FRM) is therefore essential to at-risk communities (Wehn *et al*. 2015).

1.2 A shift towards integrated flood risk management

Historically, rivers have often been constricted, modified and disconnected from their floodplain as a result of hard engineered flood defences (Albrecht, 2016). Methods such as river straightening, embankments, together with intensification of agriculture, have had a negative impact of flood risk and water quality (Albert *et al*. 2019). They have also reduced the amount of potential water storage available, which may contribute to increased flooding within downstream settlements (Pattison and Lane, 2011). Further issues arising as a result of river modification are increased sedimentation, scour, bank erosion and invasive species habitat creation (Archer, Bathurst and Newson, 2016).

In the UK, as a result of various policies and reports, such as the Department for Environment, Food and Rural Affair's (DEFRA) "Making Space for Water" (2005) and the Pitt review (2008), the focus of flood risk management (FRM) has moved towards a more integrated approach. It has been recognised that structural measures alone cannot mitigate against flood risk. Therefore, it has been realised that it is not economically, socially or environmentally acceptable to build ever-taller defences against floods (Hankin *et al.* 2016). Thus, integrated flood risk management (IFRM), which considers a wider range of aspects influencing flood risk, including land use planning, flood preparedness and community resilience, is a preferred option (Chappell, 2006).

Following the recognition that structural measures alone are not capable of mitigating flood risk, additional methods have been sought (Hankin *et al.* 2016). Natural flood management (NFM) is part of IFRM and defined as a strategy which aims to work with natural hydrological processes to retain and slow water within the upper catchment whilst creating wider benefits beyond FRM such as habitat creation, diffuse pollution reduction and sediment capture (Nicholson *et al*. 2012; SEPA, 2016). It has emerged as a result of policy change, the need for non-structural FRM methods, and a desire to create maximum outputs for economic inputs.

Previous examples of NFM projects have highlighted some success in reducing flood risk. For example, research within the Belford, Pontbren and Pickering projects has demonstrated reductions in overland and peak flows (Metcalfe *et al.* 2017; Jackson *et al.* 2008; Nisbet *et al.* 2015). Furthermore, policy has shifted more focus towards improving the ecological and chemical status of UK watercourses, and so methods which aim to improve such conditions whilst mitigating flood risk are becoming increasingly popular within FRM projects (Collentine and Futtier, 2016). However, following a national review of the evidence, it was demonstrated that research gaps, such as a lack of evidence to show the impacts of NFM at a larger catchment scale, still exist (Burgess-Gamble *et al.* 2017). Therefore, more research is required into the flood risk benefits of NFM. As a result, one of the aims of this research is to contribute knowledge towards this research gap.

1.3 Barriers to natural flood management implementation

In addition to a lack of hydrological evidence, there are still many socio-economic barriers, at multiple scales of governance, to the uptake and implementation of NFM. Wilkinson *et al.* (2019) state that scientific understanding of the social barriers to NFM implementation remains rare. Similarly, stakeholder engagement within current FRM is limited, which can lead to conflict and greater inequalities (Begg *et al*. 2017). This can also lead to people in an at-risk community not fully understanding the interventions that are being sought or what benefits they will create. DEFRA (2013) identified that an at-risk community's knowledge is an important consideration of a NFM project, as a lack of knowledge can lead to mistrust and a perception that NFM is a "do nothing" approach.

The role of public participation is considered important within FRM as it builds resilience, can bring additional funding and increases acceptance of the outcomes of the project whilst managing expectations (Begg *et al.* 2017). Using local knowledge to inform models and to plan intervention locations can be beneficial for practitioners, as data are gathered which could reduce model uncertainties (Hankin *et al*. 2016). This method offers the community ownership and a say over the outcome of the project which can be beneficial (Hankin *et al*. 2016, Environment Agency, 2017).

The previous experiences of a community can influence their attitudes towards NFM. Previously flooded residents within a community may see NFM as providing a lower standard of protection and therefore would prefer to have structural measures, whilst residents not at-risk may focus more on the wider benefits of NFM including aesthetical benefits (Buchecker, 2016; Fitton, Moncaster and Gurtherie, 2015). This may create a divide in the community and so effective engagement and knowledge transfer to prevent this is required.

Some evidence to demonstrate reductions in flood risk as a result of NFM intervention has been gathered, but more is still required to be able to calculate the cost benefit ratios needed for the allocation of public funding (Waylen *et* al. 2017; Rouillard *et al.* 2015). This poses a potential barrier for practitioners who wish to install NFM within a catchment. In Scotland, Waylen *et al*. (2017) found that practitioners recognised that, without evidence, it will be difficult to persuade landowners and the public that NFM is a viable FRM option. Landowners were considered by practitioners to be unwilling to sacrifice productive land for an unproven method of FRM that may not deliver any real benefits for the downstream community (Bracken *et al*. 2016).

It has been acknowledged that private landowners and managers must be engaged if NFM is to be successfully implemented (Wilkinson *et al*. 2019). However, the current barriers to uptake of NFM by landowners are complex. Concerns over farm economics and future maintenance of NFM interventions create significant barriers to uptake, as a farm is first and foremost a business which may not be able to afford an economic loss (Holstead *et* al. 2014). Barriers to landowners also go beyond economic concerns. For example, Holstead *et al.* (2014) found that historic traditions and ancestry influence both create a barrier to uptake for Scottish farmers. With farmers historically being paid to drain land and take water away as quickly as possible in order to maximise agricultural production, NFM may be seen as controversial as it would undo the drainage work of their ancestors. Therefore, it is recognised that complex socio-economic barriers exist to NFM uptake and implementation, which require an interdisciplinary approach in order to be overcome.

A holistic framework for analysis, which looks at the barriers within the system as a whole, is needed. One method to apply a holistic framework is the approach of Ostrom (2012). It suggests that it is important to include the resource system, governance, actors and the interactions between these in a social-ecological system. This analysis must take into account the views of multiple stakeholders. To date no research has attempted to discuss the barriers to NFM uptake across multiple stakeholders, so another research gap was identified.

Stakeholder engagement with landowners is recognised as a potential method to increase the acceptance of NFM on private agricultural land (DEFRA, 2013; Challies *et al*. 2016; Posthumus *et al*. 2008). As part of this, a method documented within the literature is to use NFM demonstration sites to improve the knowledge and understanding of NFM by landowners and in turn improve attitudes towards it (Posthumus *et al*. 2008; Mccarthy *et al*. 2018; Holstead, Colley and Waylen, 2016). This may result in a change in behaviour and therefore an increase in NFM uptake on agricultural land. However, there has been little research to measure the impact of this method, other than anecdotal evidence gathered through engagement with landowners, which presents another research gap. This is reflected within the aims and key questions of this research.

1.4 Aims and key questions

The principal aims of this thesis are to contribute knowledge to the currently limited evidence base on natural flood management (NFM) and to assess the barriers to wider implementation.

The key questions of this thesis are:

1. **Can natural flood management impact on hydrograph characteristics?**
2. **To what extent are the local community knowledgeable of NFM and how does this impact on favourability?**
3. **What are the barriers to NFM uptake nationally and how do they apply in practice?**
4. **Can land manager exposure to NFM result in changes of knowledge, attitudes and behaviour?**

The objectives relating to these key questions are:

Can natural flood management impact on hydrograph characteristics?

- To undertake a literature review and analyse past evidence of NFM impacts on flood risk.
- To implement a NFM scheme in the catchment of the Potwell Dyke, Southwell on land owned by Nottingham Trent University.
- To analyse the impact of the NFM scheme on water levels, lag times, celerity and flows in water courses.

- To analyse the potential impact of water storage on flows within the catchment.

To what extent are the local community knowledgeable of NFM and how does this impact on favourability?

- To use a questionnaire sent to the residents of Southwell to assess knowledge and favourability towards NFM.
- To assess the implications of knowledge of NFM on favourability.
- To assess the impact of previous flood experience on favourability.

What are the barriers to NFM uptake nationally and how do they apply in practice?

- To review the literature to identify barriers to the uptake of NFM.
- To conduct interviews with land managers in the catchment to identify further barriers to NFM uptake.
- To conduct interviews with professionals and practitioners of FRM nationally (England and Scotland) to identify barriers to NFM uptake from an industry perspective.

Can land manager exposure to NFM result in changes of knowledge, attitudes and behaviour?

- To communicate the findings of the NFM scheme to Potwell Dyke catchment land managers.
- To use follow-up interviews with land managers to analyse changes in knowledge, attitudes and behaviour of NFM compared to pre project interviews.
- To discuss whether using a demonstration site visit is a valid method to overcome barriers to NFM uptake.

1.5 Structure of the Thesis

Figure 1.1 shows the structure of the thesis. Individual results and discussion from each research question are discussed within Chapters 5-8.

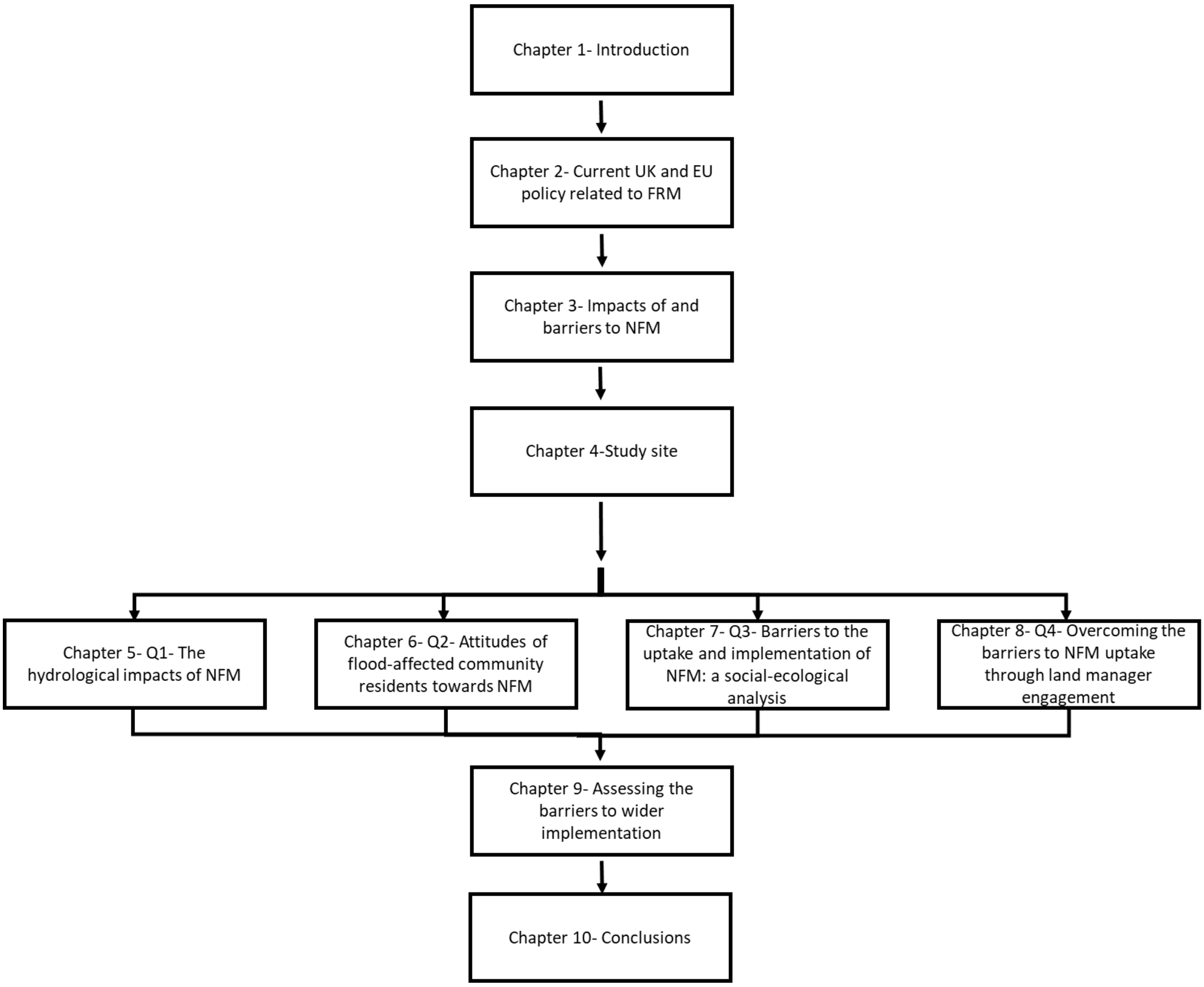

Figure 1.1 Thesis Structure

2. Current UK and EU policy related to Flood Risk Management

Before reviewing the literature, it is necessary to outline the current international policy context for UK FRM overall (at the time of writing, the UK is a member of the European Union). International FRM policies apply to the UK through directives set out by the European Union. Within this chapter, policy which relates to NFM is also reviewed in order to assess the current barriers which may be a consequence of a lack of policy.

2.1 Current policy influencing NFM

Within the last decade, multiple flood events have caused significant damage to property and infrastructure within the UK. For example, flooding events such as the summer of 2007 and winters of 2012, 2013/14 and 2015/16 have all caused property inundation and significant economic loss (Marsh *et al.* 2016). With one in six properties at-risk, flooding is the UK's most serious natural hazard, causing an estimated annual economic loss of £1.1bn (National audit Office, 2011; Thorne, 2014). However, single events can cause much more loss. For example, the summer floods of 2007 caused a loss estimated at £3.2 billion and the winter floods of 2015/16 are estimated to have caused economic losses up to £5.8bn (Thorne, 2015; Priestly, 2016).

The flooding in summer 2007 can be seen as an event that caused a turning point in UK FRM policy. The economic impacts have already been mentioned, however the flooding caused the inundation of 55,000 properties, around 7000 people had to be rescued and 13 fatalities were recorded (Pitt, 2008). The event also caused a significant loss of essential services, with half a million people left without mains water or electricity (Pitt, 2008). As a result of the event, the Pitt review was commissioned and highlighted that flooding could no longer be solely mitigate against using structural measures.

Similarly, following the winter of 2015/16 flooding event, significant damages occurred. Around 16,000 properties were flooded in December, with more flooded in January (Marsh *et al*. 2016). As a result, there was public outcry for more sustainable FRM, which forced NFM to be higher within the political agenda (Howarth, 2017). This demonstrates that recent catastrophic flooding events have placed NFM within current political debate and as a result, NFM is becoming an increasingly important subject within UK policy.

Key pieces of UK legislation have changed UK FRM policy within the new millennium towards a more integrated approach (Huq and Stubbings, 2015; Rouillard *et al.* 2015; Howarth, 2017). This shift moves FRM away from "taming the river" and structural flood defences, towards more integrated flood risk management using sustainable approaches and working with natural processes (WWNP) (Daigneault, Brown and Gawith, 2016; Environment Agency, 2012). The shift has allowed approaches to be taken which increase the overall benefits of FRM schemes such as increased community resilience or ecological gains. This chapter discusses current key legislation, which promotes NFM within the current system of governance in the UK.

2.1.1 Water Framework Directive (2000)

The WFD Water Framework Directive (WFD) (2000) is the EU legislation driving the improvement of ecological status within European watercourses and is therefore governance set at the European scale. It is the first piece of legislation which positions sustainable FRM within policy (Kenyon, Hill and Shannon, 2008) The aims of the WFD are: there should be no further deterioration in surface or groundwater status, all EU rivers and groundwaters are to reach “good” status by 2015, priority substance pollution should be reduced and any upward trend in pollution should be reversed (European Commission, 2000).

The WFD promotes the use of NFM, as ecological benefits can be an additional outcome of intervention implementation. As the WFD sets out to improve river ecology, this legislation is influential in the shift away from flood defence towards IFRM and sustainable flood management (Nisbet *et al.* 2011b).

However, the Directive can be undermined as the WFD states that where economic growth may be at-risk, rivers become exempt from the aims of the WFD (European Commission, 2000). Article 4.4 of the WFD states that if restoration costs would be a disproportionate to the benefits gained, or when the improvements would exceed the time scale which has been declared, then deadlines can be extended as long as there is no deterioration in ecological status (European Commission, 2000). Thus, although the WFD does set out to increase the use of sustainable flood management, the policy has a limitation which could potentially be exploited.

2.1.2 Making Space for Water (2005)

Also at a European scale, the DEFRA (2005) Making Space for Water report, recommended taking a more holistic approach to flood risk management. The report suggested that the UK government should take a catchment wide approach to FRM, whilst including stakeholders at all stages. The report acknowledges that protection against all flooding is not a possibility, so greater resilience and response to flooding is recommended. It is accepted that flooding is natural and should be accommodated rather than restricted (Pardoe, Penning-Rowsell and Tunstall, 2011).

The report additionally sets out principles to improve the environmental pillar within FRM, to achieve a greater balance between the three pillars of sustainability (Piper, 2014). The report recognises that rural land management can reduce flood risk and so supports the use of NFM. Therefore, this report is one of the first to directly support the principles of NFM.

2.1.3 The Floods Directive (2007)

The Floods Directive 2007 (FD) sets out a legal framework for FRM across all EU watercourses and so is also European scale governance over NFM. It requires all member states to map flood risk and to create flood management plans (Albrecht, 2016). Moreover, the directive sets a precedent to include public participation at the planning stages of a FRM project (Albrecht, 2016). The directive adds to the WFD (2000) as it also promotes ecological gains within watercourses. However, the two directives can contrast as well as compliment. Natural measures to reduce flood risk can improve ecological status, yet channel modifications to reduce flood risk can reduce ecological status, and as both are incorporated within these policies, a conflict is presented (Hartmann and Spit, 2016a).

As the FD is legally binding to member states, the policy must be incorporated into current member state policy. However, it has not been made clear how this will be achieved (Hartmann and Spit, 2016b). As a result, the UK has only incorporated the key elements into its FRM policy such as risk mapping, greater working with natural processes and public participation (DEFRA, 2009). This greatly limits the effectiveness and influence of the directive. Furthermore, with member states implementing the FD in a heterogeneous fashion, problems may arise in areas where rivers cross national boundaries if cohesion is not created between neighbouring member states (Hartmann and Spit, 2016b). However, it is concluded that the FD does influence UK FRM policy and NFM despite its limitations.

2.1.4 Pitt Review (2008)

Following the 2007 summer floods, the Pitt review (2008) aimed to conduct a review of the lessons learned from the flooding event. The national scale review commented that a lack of organisation and responsibility within FRM governance was a hindrance. As a consequence, the review recommended the national overview of flooding should be given to the Environment Agency. However, recommendation 14 gives the local authorities lead over local flood risk (Pitt, 2008). These recommendations not only delegate responsibility but let local decisions be made by local authorities, which in turn increases stakeholder engagement (Huq and Stubbings, 2015).

Recommendation 27 of the review is to make a move away from structural flood control measures and towards methods which work with natural processes to reduce flood risk (Environment Agency, 2012). This encouraged the paradigm shift within FRM policy previously discussed, as the review promoted the use of NFM as part of FRM schemes and further supports the DEFRA (2005) report.

Although the Pitt review gave many recommendations, not all have been adhered to. Recommendation 11 suggests that all new housing in areas of flood risk should be built with some resilience measures installed (Pitt, 2008), yet currently this is not being implemented. Flood resistant housing installed with property level resilience (PLR) could reduce the risk of interior flooding to many, whilst promoting FRM as a private rather than public good (Geaves and Penning-Rowsell, 2015). This could help to promote risk awareness and resilience, which currently does not exist within some households.

2.1.5 Flood and Water Management Act (2010)

The Flood and Water Management Act (2010) established key FRM responsibilities for authorities and creates cooperation and communication between authorities involved within FRM. Therefore, it has governance over FRM at a national scale. There are two types of river identified within this Act, Main Rivers and Ordinary Watercourses. Main Rivers are larger rivers whilst Ordinary Watercourses are smaller watercourses such as ditches, drains and dykes. The EA were stated to have responsibility over flooding from main rivers and are obligated to publish a strategy for flood and coastal erosion risk management. The Act also initiated the creation of Lead Local Flood Authorities (LLFA) and appoints responsibility for ordinary water course and surface water flooding to the LLFA.

Section 38 stated that, if three conditions are met, the EA can carry out works which may cause flooding. The conditions are: 1) the EA consider the work of interest to nature conservation, cultural heritage or people's enjoyment. 2) benefits will outweigh costs. 3) the EA consults the LLFA, district council, internal drainage board and persons who own or occupy land which is to be affected by the work. This section therefore allows the temporary flooding of upstream areas, which demonstrates an acceptance of NFM techniques by UK policy. In addition, the Act encourages FRM decision makers to include NFM techniques within FRM strategies where applicable and lists "*maintaining or restoring natural processes*" as a flood mitigation method. Hence, NFM and WWNP became a greater part of FRM policy in the UK as a result of this Act.

2.2 Polycentric governance of NFM

Polycentric governance is defined as the governance over an issue from multiple centres which range in scale and overlap (Ostrom, 2012). This is applicable to NFM as decisions for implementation are influenced from multiple scales of governance and often, interactions between each scale of governance occur (see Figure 2.1). At the largest scale, EU legislation such as the Water Framework

Directive (2000) and the Floods Directive (2007) influence NFM uptake as greater working with natural processes is sought, which should bring multiple benefits such as ecological gains. At a national scale, the need for new scientific evidence and understanding of NFM as a flood risk management (FRM) method is driving new NFM projects and funding; such as the £15 million announced by DEFRA in 2016 (Leadsom, 2016). At a local or regional scale, the LLFA are tasked with FRM under the Flood and Water Management Act (2010). Thus, as the LLFA have derestriction over ordinary watercourses, and ordinary watercourses are often found within the upper catchment, NFM is likely to be installed through LLFA decision making as a result. However, NGOs may be involved when implementing NFM as they can build good relationships with landowners and have a better understanding of the farm business.

At a smaller scale, decisions for NFM implementation can come through communities (Bracken *et al*. 2016). Local flood action groups who would like NFM within their catchment can influence NFM uptake though active cooperation with landowners, the LLFA and the Environment Agency (Green and Penning-Rowsell, 2010). This links to the smallest scale, the individual landowners and managers themselves. An individual landowner who decides they want to implement NFM for the good of the community, has to overcome barriers within these scales of governance.

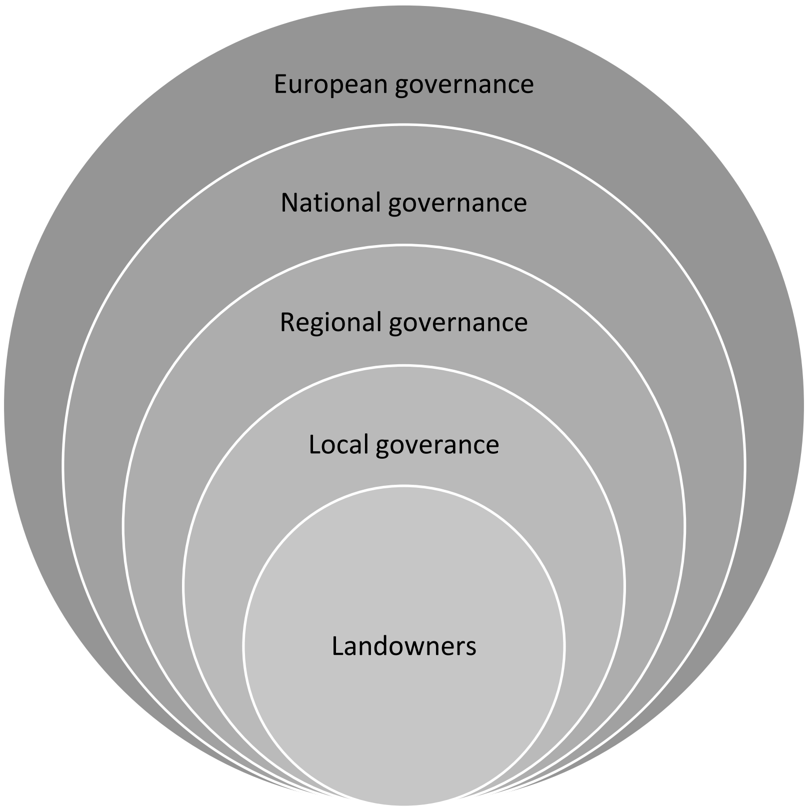

Figure 2.1 Polycentric governance of natural flood management uptake.

2.2.1 Governance at a European scale

At the European scale, NFM is driven by EU policy. These are mainly the Water Framework Directive (WFD) (2000) and the Floods Directive (2007). Whilst the WFD does not explicitly encourage the use of NFM or related concepts, it aims to improve the water quality and ecological status within European watercourses (Werritty, 2006). As NFM can deliver multiple benefits beyond FRM such as diffuse pollution reduction, sediment capture and habitat creation (SEPA, 2016; Janes *et al*. 2106; Abbe, Brooks and Montgomery, 2003), the WFD has been influential in NFM implementation.

Unlike the WFD, the Floods Directive (2007) directs decision makers towards more integrated flood risk management including NFM. This includes working with natural processes and accommodating water on the floodplain, rather than restricting a watercourses ability to flood (Hartmann and Spit, 2016). Yet, as the directive does not state how to implement these measures, it is left to the member state to decide how best to implement interventions (Hartmann and Spit, 2016). As a result, a majority of the barriers to implementation are shifted to the smaller scales of governance. For this reason, this research mainly focuses on governance ranging between the national and individual landowner scales.

2.2.2 Governance at the national scale

At a national scale, DEFRA is the "*lead Government Department for flood emergencies in England*", and the Environment Agency is "*the principal flood and coastal risk management operating authority in England"* (DEFRA, 2014: 26). Therefore, DEFRA has a responsibility to maintain national flood resilience and link between the department and central government on flooding related issues. DEFRA provide funding through Grant in Aid for FRM projects, which may include elements of NFM, and so they have a significant part to play in NFM implementation. This has been demonstrated with the funding of three experimental NFM projects and the £15 million announced for funding NFM projects within the UK (Barlow, Moore and Burgess-Gamble, 2014; Leadsom, 2016). This funding focuses on two types of projects; community based and catchment based. The community based projects receive a smaller amount of funding and so less scientific evidence gathering is required. The aim of the catchment based projects is to gather scientific evidence through NFM installation and so more funding is allocated for these.

Meanwhile, the Environment Agency are stated to have responsibility over main water course flooding which is incorporated into the Flood and Water Management Act (2008). As NFM interventions may be suited to some main rivers, the EA has governance over NFM implementation in such areas. Therefore, through the responsibilities set out for the EA, the body has governance at the national scale.

2.2.3 Governance at regional scale

Funding for FRM is applied for at a regional scale though a Grant in Aid application to DEFRA (Begg *et al.* 2017). However, DEFRA no longer fully funds FRM in the UK, and so match funding must also come from other parties such as local councils, businesses and residents; this is termed partnership funding (Begg *et al.* 2017). The regional flood and coastal committee (RFCC), which is made up of local stakeholders with an independent chair, allocates funding based on a cost benefit analysis which demonstrates the benefits gained from a unit of expenditure (Begg *et al.* 2017).

As previously mentioned, the Flood and Water Management Act (2010), states the LLFA as responsible for local flood risk. The LLFA, as set out within the Flood and Water Management act (2010), is the county council. At a regional scale, the LLFA has governance over FRM and therefore NFM. Moreover, as ordinary watercourses are often located in the upper reaches of the catchment where NFM is considered most effective, LLFA's have a significant role within uptake and implementation.

However, NGO's are becoming more commonly involved within NFM implementation at this scale when wider benefits are sought (Thaler and Priest, 2014). NGO's often have agendas beyond NFM and so can find funding through other streams such as biodiversity enhancement or pollution reduction (Wheeler, Francis and George, 2016). Combined with their approachability towards landowners, NGO's are becoming more important within NFM implementation and so some governance over NFM lies with them.

2.2.4 Governance at a local scale

Flood action groups are commonly set up, often following a flood event, to give the local community influence over some flood related issues. They are becoming increasingly involved within FRM in the UK, generating funding through partnership funding initiatives, whilst giving local actors a voice (Thaler and Priest, 2014). Partnership funding aims to shift some costs of FRM to the public or private beneficiaries, thus creating a system that outputs both public and private benefits with regards to FRM (Greaves and Penning-Rowsell, 2016). This may in turn raise risk awareness and change behaviour, as previous funding strategies reduced risk perception due to the public expectation of protection (Hartmann and Spit, 2016). Current partnership funding schemes have created a larger involvement of the community within many aspects of FRM including design (Greaves and Penning-Rowsell, 2016). In turn, wider success is achieved alongside a greater level of acceptance as more people can benefit from a scheme (Greaves and Penning-Rowsell, 2016; Hartmann and Spit, 2016). Moreover, through partnership funding, communities are given the opportunity to govern their own flood risk which may contain elements of NFM. Therefore, the local community is recognised as having local governance over NFM within this research.

Although the benefits of partnership funding and local stakeholder involvement are recognised, literature suggests that there could be some negatives which arise as a result of local FRM action. Green and Penning-Rowsell (2010) discuss these in more detail. For example, it is important to consider the relationship between non-elected members of power and elected officials as vested interests could arise. These negatives are discussed in more detail within section 3.6.1.

2.2.5 Individual landowners

Individual landowners are seen to have the smallest scale of governance but are often the key decision maker within NFM projects. If a landowner is unwilling to uptake NFM on their land, then ultimately the NFM project may fail. Therefore, landowners have a crucial overview of the governance of NFM projects in practice and so research questions within this research have been considered to reflect this.

The next chapter will review the literature on the impacts of NFM on FRM as well as the barriers to NFM uptake.

3. Impacts of and barriers to NFM: a literature review

3.1 Introduction

Natural flood management manages flood risk by restoring and protecting the natural hydrological processes of the environment (Barlow, Moore and Burgess-Gamble, 2014). NFM is split into three categories: managing infiltration, managing connectivity and managing storage (Holstead *et al*. 2014). This can be achieved through land use change such as afforestation or online and offline storage creation through methods such as large woody debris (LWD) introduction or bunding (SEPA, 2015).

As NFM methods are relatively cheap when compared to structural measures, NFM is being increasingly implemented in areas where the cost benefit ratio is not high enough to justify structural measures (SEPA, 2016). NFM is also considered a useful option in areas where the river is constricted, such that structural measures are not feasible due to the spatial restrictions (Nicholson *et al.* 2012). Many forms of NFM intervention exist, with each intervention type presenting its own benefits and limitations.

This literature review discusses the research to date related to the four key questions set out within the introduction. Currently, the main types of NFM interventions being implemented are large woody debris (LWD), bunds, river restoration, wetland creation, afforestation and other land management practices intended to slow the flow of water into the watercourse (Burgess-Gamble *et al.* 2017). As NFM is not simply a hydrological process, socio-economic factors also need to be recognised and discussed in order to understand the barriers to uptake and implementation of NFM interventions. In order to achieve this, an interdisciplinary research approach is required to better understand the full range of challenges faced.

This review follows the four key questions of the thesis in order to give a clear overview of the literature relating to each question. The research gaps found from the literature review are then discussed.

3.2 The theoretical impact of natural flood management on the hydrograph

Natural flood management aims to shift discharge from the peak of the hydrograph to the falling limb (Thomas and Nisbet, 2007). In turn, peak discharge is reduced whilst discharge during the falling limb is increased (Figure 3.1). NFM does not aim to reduce the total discharge during an event but only to change the shape of the hydrograph to reduce peak discharge. Other desired impacts as a result of NFM intervention on the hydrograph are to increase lag times between peak rainfall and discharge, but also to decrease celerity of the peak though the slowing of flows within the channel (Sholtes and Doyle, 2011). As shown in Figure 3.2, although NFM interventions are most likely to have local impacts, NFM offers opportunity to desynchronise catchment tributary timings and therefore further reduce peak flows, if the lag time between peak rainfall and peak discharge is increased (Pattinson *et al.* 2014).

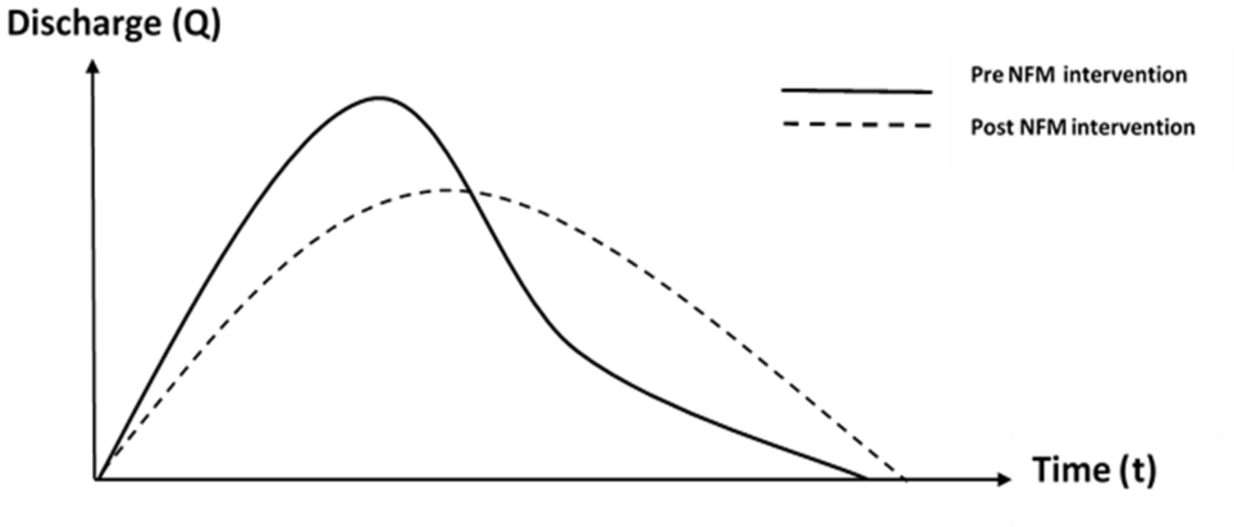

Figure 3.1Theoretical hydrograph showing attenuation post NFM intervention. Modified from Thomas and Nisbet (2007).

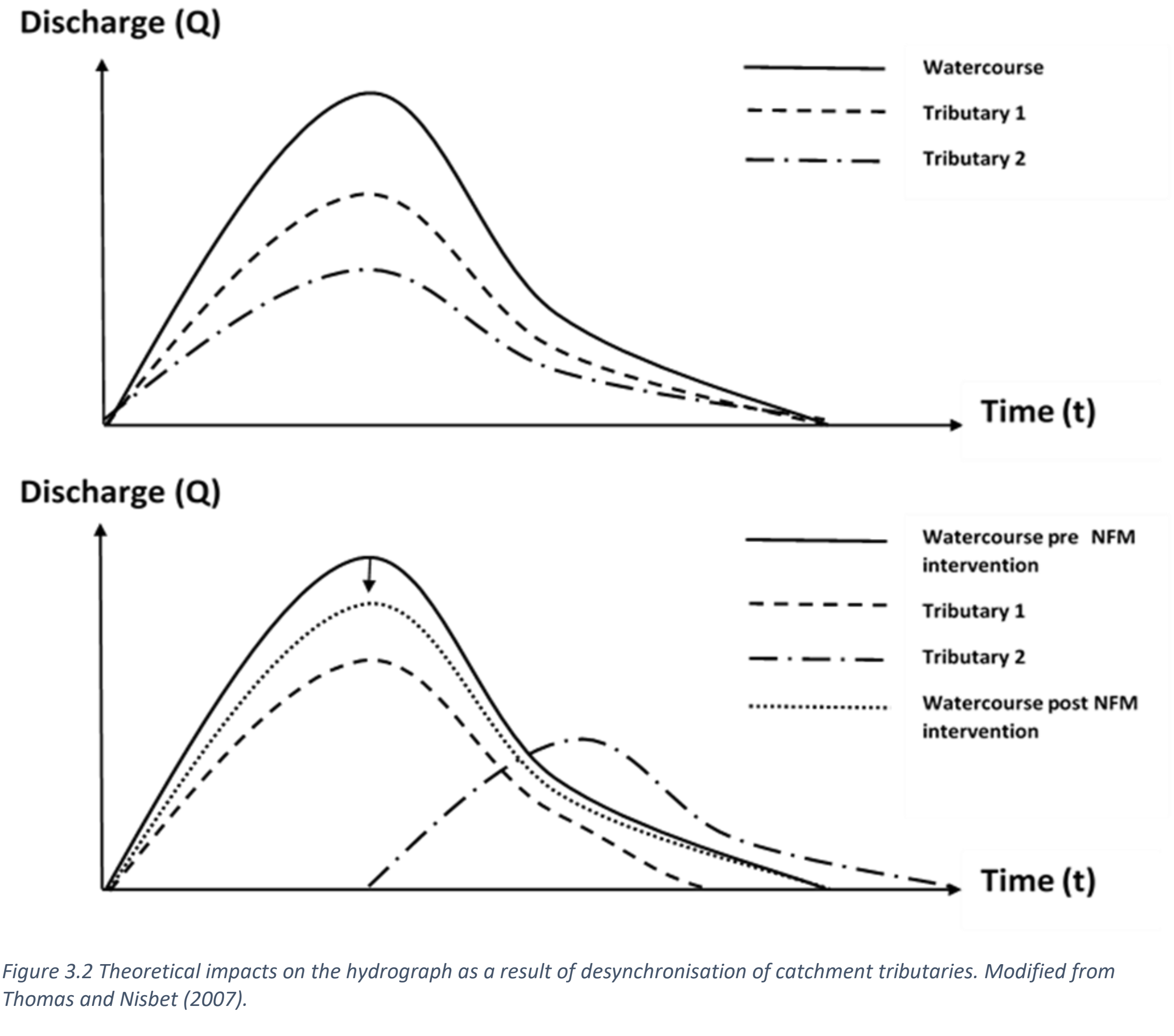

Figure 3.2 Theoretical impacts on the hydrograph as a result of desynchronisation of catchment tributaries. Modified from Thomas and Nisbet (2007).

3.3 The nature and scope of natural flood management in the UK

3.3.1 Large Woody Debris Dams

Large woody debris (LWD) (also referred to as engineered log jams or leaky barriers) are generally defined as pieces of wood greater than 0.1m in diameter and 1m in length (Linstead and Gurnell, 1999). These are usually placed within natural watercourses and can reduce flood risk in two ways. First, the introduction of LWD has a primary FRM benefit in that it creates storage capacity behind the dam and connects the channel to the floodplain (Dixon *et al.* 2016). Second, the introduction of LWD creates roughness within the channel which results in a higher Manning's n value and thus lower velocities and discharge during events (Linstead and Gurnell, 1999). Although the effects of one LWD dam on FRM may be insignificant, when installed in succession the effects can become cumulative and therefore significant (Linstead and Gurnell, 1999).

LWD is now being widely introduced into UK watercourses under NFM activities, but it is imperative that the literature is used to inform projects on the appropriate quantities, location and designs which should be used to mimic natural processes (Gurnell, England and Burgess-Gamble, 2018). LWD dams are often cheap to construct and require little resources to build, meaning they can be a cost effective short to medium term FRM intervention (National Trust, 2015). LWD should be designed to let low flows pass unimpeded yet once higher flows begin, the dams should become active and store water (Thomas and Nisbet, 2012). This allows for the storage within the LWD to be available for a second event but also allows for the passage of migratory fish (Dodd, Newton and Adams, 2016). LWD has many wider benefits beyond FRM such as habitat creation, refuge during high flows, sediment capture and agricultural pollutant capture (Abbe, *et al.* 2003; Janes *et al*. 2016; Linstead and Gurnell, 1999). When combining LWD with riparian planting, the capture of smaller pieces of wood flowing over the bank increases, alongside bank roughness and future in-channel wood recruitment (Gurnell, England and Burgess-Gamble, 2018; Linstead and Gurnell, 1999).

At Pickering, North Yorkshire, natural flood management has been used alongside engineered structures to reduce flood risk. LWD dams were calculated to have a combined storage capacity of ~1,020m^3 during a 1 in 25 year event (Nisbet *et al.* 2015). Findings suggested that placing 104 LWD dams at the site had reduced flood flows by 7.5% and worked to store water as expected during the 2015 boxing day high flow event (DEFRA, 2013; Forestry Commission, 2016). Odoni and Lane (2010) found through a modelling study based at Pickering that the impacts of LWD increased as event magnitude increased due to their design letting low flows pass. This was stated as unusual given the current consensus that NFM effectiveness decreases as event magnitude increases.

Kitts (2010) conducted a study in the New Forest, South England using upstream and downstream loggers on a restored reach which had LWD installed and a control reach which did not, in order to calculate the passage of the flood wave through the system. Large wood densities were found to alter the timing of the flood peak from an average of 1 hour 35 minutes to 2 hours 10 minutes (2.2 year return period). Within the same research, modelling found that LWD can increase floodplain inundation by up to 175% and inundation time by up to 156% when compared to other river sections of the same reach. However, the study concluded that further monitoring is needed to analyse the impacts of LWD on larger flood events as they were not experienced over the course of the research.

In contrast, Sholtes and Doyle (2011) modelled the impacts of short channel restoration including simulated hydraulic roughness increases which could be applied to LWD introduction. It was found that there were only small impacts on flood attenuation (<1%) if stream reach restoration was

0.9km. Larger scale interventions (5-10km) were found to be needed to see a catchment wide reductions in flood risk.

Although evidence derived from modelling studies into the impact of installing LWD dams exists, only one empirical study is documented within the Working with Natural Processes evidence base (Burgess-Gamble *et al.* 2017). Wenzel *et al*. (2014) simulated flow events by opening a reservoir sluice. Simulated flows of a 3.5 year return period were created within a 282m stream and hydrograph outputs with and without LWD dams were compared. It was found that the introduction of LWD (spruce trees) within the stream reduced flood wave progression velocity from 0.45 m/s to 0.38 m/s (15.5%). Peak discharge was found to have reduced from 183 ls^{-1} on average to 179 ls^{-1} (2.2%). Furthermore, the hydrograph shape changed to match the theory discussed by Thomas and Nisbet (2007). A longer falling limb was observed as 29.7m^3 (22%) of the total flow volume was shifted, meaning the duration of high flows decreased. Yet the study was considered limited as the experimental event may not transfer to natural conditions. As a conclusion, it was recommended that LWD should be tested under real meteorological and hydrological conditions.

There are additional gaps within the evidence directory which highlight limitations to LWD as a FRM measure (Burgess-Gamble *et al.* 2017). At present there is limited guidance on the construction and maintenance needs of LWD dams. Furthermore, little research has been conducted on their design life to suggest when dams may need replacing. Once submerged, the effects of LWD dams on flood risk diminishes, so careful spatial planning and design is required so that dams within succession do not drown upstream LWD dams (Nicholson *et al.* 2012). There is also a current lack of understanding of the effect of tree species and its impacts on fluvial processes (Gurnell, England and Burgess-Gamble, 2018). Little is known on which species are better suited to sustainable NFM intervention.

Practical considerations of LWD intervention are suggested within the literature. For example, LWD must be anchored or secured in some way to limit movement (SEPA, 2016; Linstead and Gurnell, 1999). The type of watercourse must also be considered. Gurnell, England and Burgess-Gamble (2018) state that watercourses with high energy may mobilise LWD too often. It is suggested within this paper that LWD which spans 2.5 times the channel width becomes near immobile and so this consideration should be taken into account where mobilisation of LWD is undesirable. If LWD does become mobile, it can block structures such as trash screens or culverts and increase flood risk.

Additionally, Dodd *et al*. (2016), found that some designs of LWD dam can be barriers to fish movement if sufficient space is not made available for fish to pass underneath. If considerations for such issues are not included within the design of LWD as a NFM intervention, negative ecological impacts can be a potential consequence. Over time, sedimentation and wood recruitment will stabilise LWD dams but maintenance is advised so that dams do not become too efficient and prevent water passing through. Maintenance is especially advised on steeper reaches, where scour may be increased (Thomas and Nisbet, 2012), and after large flow events to assess any damage or movement of the dams (Forestry Commission, 2016).

3.3.2 Bunding

Bunds are offline storage features that are built into the landscape to retain runoff (for a short period of time) generated through overland flow (SEPA, 2016). They should be located in areas where runoff paths are present, in order to intercept them. This can be determined using topographic analysis combined with field surveys (Nicholson, *et al.* 2012). The design should allow for the bund to drain down over a time which is long enough to delay runoff inputs into watercourses, but short enough to allow for the storage capacity to be available for the next event

(Nicholson, *et al.* 2012). Bunds can be constructed by scraping soil into a mound or by installing timber, although timber bunds at Belford (Northumbira) were estimated to cost 5-7 times as much as soil scraped bunds (Wilkinson, Quinn and Welton, 2008).

Studies which have successfully demonstrated a reduction in flood risk using bunds are limited. A report on the Holnicote project suggested that a network of bunded storage areas helped to deliver a reduction in flood risk of 10% for an event in 2013 (National Trust, 2015). However, this percentage figure is not quantified nor are the methods used to derive it defined. Although modelling studies have demonstrated receptions in peak flows, empirical studies are lacking. This is highlighted by Burgess-Gamble *et al.* (2017) as a research gap which needs addressing.

At Belford, Nicholson *et al.* (2012) found that bunding stored runoff water and that bunds drained down within a period of 3-5 hours. Quinn *et al*. (2013) also studied the impact of runoff attenuation features in Belford using the Pond model. It was found that that the peak flow reduction of 35 storage areas (totalling 19,250 m^3 of storage) is calculated to be between 15% and 30%. However, the findings also highlight the importance of understanding the critical number of bunds required to significantly affect peak flows within a catchment.

Bunding has also been used at the Pickering project with success. The bund at Pickering has a storage capacity of 120,000m^3 and reduces the annual risk of flooding from 12% to 4% (Nisbet *et al.* 2015). Although, it must be noted that the bund at Pickering is large enough to be subject to the Reservoirs Act (1975) requiring annual inspection by a qualified engineer (Wilkinson, Holstead and Hastings, 2013). As a result, it is heavily engineered and so it is questionable if this feature fits under the NFM label. Nevertheless, during the 2015 Boxing Day event the NFM measures at Pickering, including the bund, were concluded to have reduced flooding impacts within the local town as peak flows were reduced by $2m^3s^{-1}$ (Forestry Commission, 2016).

Bunds have wider benefits beyond flood risk management; they can capture sediment and therefore reduce pollution into watercourses from agricultural runoff (SEPA, 2016). Yet, for this reason limitations to bunds exist as captured materials will need to be removed from inside the bunds (Burgess-Gamble *et al.* 2017). This is required to avoid over siltation and maintain storage capacity of the interventions (Wilkinson *et al.* 2014). Furthermore, bunding is often located in agricultural fields and so landowner consent is required. As mentioned previously, bunds are located in areas where they can intercept runoff. These areas are often the wettest areas of the farm and can often be in the corner of fields. Therefore, loss of productive can be minimised through considerate design.

3.3.3 River Restoration

River restoration as a FRM measure aims to return a river to a pre-defined natural state in order to increase hydraulic resistance and potential storage (Dixon *et al.* 2016; Gurnell, 2014). Design considerations are important to ensure a planform which will function naturally in terms of geomorphology, sedimentation and scour (Beechie *et al.* 2010). If restored correctly, a restored river should be self-sustaining and require less maintenance.

Historically, rivers have been modified and disconnected from their floodplain as a result of hard engineered flood defences (Kristensen *et al*. 2014). This has reduced the amount of potential storage available which may contribute to increased flooding within downstream settlements (Pattinson and Lane, 2011). Potential storage has been reduced in two ways: a decrease in sinuosity and therefore channel length, and the loss of floodplain connection. Therefore, the amount of water that can be stored in the channel itself is reduced and disconnection from the floodplain reduces online and offline storage capacities (Charlton, 2008). Disconnection from the floodplain additionally reduces channel roughness during events, as riparian vegetation is bypassed by flood waters (Sholtes and Doyle, 2011).

Evidence to demonstrate the effectiveness of river restoration as a FRM measure is growing, yet there is still a lack of consensus. Sholtes and Doyle (2011) argue that river restoration would only be effective during low and medium magnitude events and that during extreme events, it would be an ineffective FRM measure. Their study which modelled short lengths of restoration (~0.9km) to simulate higher channel resistance, concluded that there were minimal effects on attenuation (<1%) and so the restoration of 5-10km would be needed so see effects.

Acreman, Riddington and Booker (2003) found that embanking a river increases the peak flows downstream by 50-150%. Yet, restoring the river channel through the floodplain to a pre-defined state can reduce peak flow by around 10-15% and increase peak water levels within the floodplain by 0.5-1.6m. Bormann *et al*. (1999) similarly found that restoring the river planform to a meandering planform reduced peak discharges downstream through the creation of a longer channel length. Additionally, in channel plant growth was found to reduce peak flows through increased channel roughness.

The ecosystem services provided by river restoration are significant and can often be the driver for its implementation (Dixon *et al.* 2016). Through river restoration, greater ecohydraulic diversity is created which improves in stream habitat quality (Gilvear, Spray and Casas-Mulet, 2013). Installing online storage areas such as oxbow features not only provides additional flood water storage, but also creates additional habitat and refuge areas for fish and invertebrates. Furthermore, river restoration can decrease pollution and sediment pollution for downstream reaches (Janes *et al.* 2016).

Limitations of river restoration include costs, disruption to wildlife and enhanced sediment inputs due to the initial disturbance of soils (SEPA, 2016). As the construction is intrusive, wildlife may be disturbed as a result of the works. Contractors and heavy machinery are often required to undertake earth moving works which can be expensive. Also, disturbance of the soil and the creation of exposed banks can increase soil erosion and therefore sediment inputs (SEPA, 2016). It is recommended that banks on newly restored watercourses are vegetated as soon as possible after intervention, and earth moving is kept to a minimum (SEPA, 2016).

3.3.4 Wetland Creation

Wetland creation aims to establish wet areas of ground, either on the floodplain through floodplain lowering, or in other areas such as agricultural land through drain breaking (SEPA, 2016). Smaller wetlands can be created using simple methods such as drain blocking or excavation of small areas of land (Avery, 2012). As a result of wetland creation, offline and online storage can be increased. Though the establishment of increased vegetation in wetlands, floodplain and channel roughness can be increased (Morris *et al.* 2008). Design has to be carefully thought out as location, groundwater status, flow regimes and runoff processes have to be considered before establishing a wetland as part of a NFM scheme (SEPA, 2016).

This is a lack of literature which provides evidence for reductions in flood risk as a result of wetland creation. Although anecdotal evidence exists, scientific hydrological evidence to support reductions in flood risk as a result of wetland creation is still extremely limited. Evidence may be lacking due to the fact that wetland creation is expensive when compared to other NFM measures and requires a higher level of ongoing maintenance and management (Avery, 2012).

A study by Kenyon, Hill and Shannon, (2008) found that an expert panel considered the draining of ponds and wetlands "very responsible" for increasing flood risk. A modelling study on the river Devon, Clackmannanshire was based on a restored floodplain wetland of 1.75ha (Ball, 2008). The hydrological findings indicated that peak flow was reduced by 11% after drain blocking and woodland was restored. However, the size of the storm event was not stated within this research.

The wider benefits of wetland creation is discussed in greater depth within the literature. Iacob *et al.* (2014) state that wetlands offer very few disbenifits and offer wider regulating and supporting services. Pollutant removal and sediment capture can be significantly increased as a result of in stream wetland creation. For example, Evans *et al*. (2007) found that nitrogen levels were reduced by 20%-70% by the installation of storm water wetlands. In summary wetlands are considered as highly productive ecosystems, which offer a wide range of ecosystem services (Avery, 2012; SEPA, 2016).

3.3.5 Afforestation

Afforestation aims to increase infiltration into soils, increase interception and evaporation but also provide roughness to the floodplain and channel to increase attenuation and reduce conveyance (Dixon *et al*. 2016; Wheater and Evans, 2009). Additionally, inputs of LWD can be increased through riparian afforestation which as discussed before can have further benefits for FRM and aquatic biodiversity (Linstead and Gurnell, 1999).

Evidence to support afforestation as a FRM measure is developing. Although it is generalised that deforestation increases flood peaks, for example a study by Troendle and Kind (1985) found that a reduction of forest cover within a catchment by 40% resulted in increased flood peaks, not all studies agree on the possible impacts on flood risk that afforestation may have (Andreassian, 2004).

Catchment afforestation has been modelled for the Potwell Dyke and Halam Hill catchments in Southwell by JBA Consulting (2017). Within the study, 5, 25, 50 and 75 year events are modelled over 1, 4 and 10 hour durations with conifer and broadleaf options modelled. It was found that higher magnitude events were not impacted due to the houses being at-risk from pluvial flooding. However, 16 properties were removed from flood risk during a 75 year event if 150ha (26%) of woodland was created in upper catchment.

The report also aimed to assess the cost-benefit ratio of woodland planting and economic viability was determined by per hectare cost of woodland planting compared to economic losses from flooding. It must be noted that no land purchase costs are included in the cost benefit analysis. It was found that flood benefits outweigh the planting costs with a benefit-costs range between 1.0 to 8.3 depending on if a low, medium or high cost scenario was chosen, which are highlighted within the report. It was concluded that to maximise cost benefit, compensation costs need to be minimised but also environmental benefits need to be quantified.

Thomas and Nisbet (2007) modelled riparian afforestation on a 2.2km reach of river and found that a 50ha woodland in a 84km^2 catchment slowed flows buy 30-140 minutes during a 1 in 100 return period flood event. Attenuation was also increased by 15-71% and a backwater effect that extended almost 400m upstream was created as a result of riparian afforestation. Similarly, Dixon *et al*. (2016) modelled the impacts of riparian afforestation and found that riparian forests at a sub catchment scale (20-40% of the catchment) could reduce peaks by up to 19% through tributary timing desynchronization. All of these studies suggest that afforestation could be part of the future FRM armoury with riparian planting offering the greatest FRM gains.

The Coalburn project in the Kielder Forest, was implemented in 1967 and is Britain's longest forest hydrology experiment (Birkinshaw, Bathurst and Robinson, 2014). It has been found that whilst larger trees reduce flows more than smaller trees, during bigger events this difference is less significant (Birkinshaw, Bathurst and Robinson, 2014). Research by Farley, Jobbágy and Jackson (2005) supports this and further suggest that maximum runoff reductions are achieved 15-20 years after planting, meaning that there is a significant time delay before intervention and FRM benefits being realised. A practical limitation is presented as forests take a long time to mature and become an effective FRM measure, unlike other NFM interventions such as LWD or bunds which have immediate impacts (Dixon *et al*. 2016; Farley, Jobbágy and Jackson, 2005; Birkinshaw, Bathurst and Robinson, 2014). As a result, FRM benefits from afforestation are often difficult for stakeholders to understand as they are not immediate and tangible. Therefore, stakeholders may not be prepared to wait a period of years or decades to see the benefits that afforestation has in terms of FRM (Iacob *et al.* 2014).

It has also been stated that afforestation may reduce peak flows for small summer events, but for larger winter events reductions may be very limited (Archer, Bathurst and Newson, 2016; Iacob Brown and Rowan, 2016). The Plynlimnon case study (Wales) compliments this finding, suggesting that although flood peaks for smaller events were reduced, for larger events reductions in the flood peak were not statistically significant (Archer, Bathurst and Newson, 2016). Iacob Brown and Rowan (2016) discussed similar findings and though a modelling methodology, concluded that some reductions in peak as a result of catchment afforestation were identified. Yet, in light of climate change these would be negligible, and so future FRM projects involving afforestation would require a combination of structural measures alongside tree planting.

Although there is a lack of consensus over the effectiveness of afforestation as a FRM measure, the benefits that are gained beyond FRM are widely recognised. Forests offer benefits such as habitat creation, carbon sequestration, air pollution reduction, health benefits and aesthetic value (Iacob *et al.* 2014; Powe and Willis, 2004; woodland Trust, 2015). Therefore, by promoting the wide range of wider benefits that afforestation offers, support for afforestation can be increased (Buchecker, Ogasa, and Maidl, 2016).

However, evidence to support reductions in flood risk as a result of afforestation at a catchment scale is lacking (Thomas and Nesbit, 2007). Few studies have demonstrated the impacts on flood risk from planting, but all demonstrate reduction in peak flows (Burgess-Gamble *et al.* 2017). Although studies do indicate successful attenuation and peak reduction as a result of afforestation at the sub-catchment scale, studies suggest only small scale events will be mitigated against (Marshall *et al.* 2009).

A literature review by Stratford *et al.* (2017) highlighted further gaps within the evidence. The study took into account the result from 56 case studies using single catchment case studies (change over time) and 15 from paired catchments (change between catchments following intervention in one). Within this, 45 studies related to increasing tree cover and 26 to decreasing tree cover. The results show there is a broad conclusion that increasing tree cover decreases peak discharge whilst decreasing cover increases peak discharge. It was also found that increasing tree cover has more impact on small events. However, using results from observational studies and excluding modelled studies makes the results less conclusive.

Finally, as demonstrated by the examples above, large amounts of the catchment require afforestation for effects on FRM to be noticeable. This would require afforestation of land which currently has other valuable land uses and so without proper compensation, afforestation at such a large scale will not be feasible (Holstead *et al.* 2014; Iacob Brown and Rowan, 2016). Moreover, planting woodland over large areas of land may have environmental trade-offs such as a reduction in Q_{95} flows which could degrade the ecological status of a watercourse (Iacob Brown and Rowan, 2016).

3.3.6 Land management

Land management practices such as buffer strips, grassland creation, soil management plans and livestock management are widely recognised as methods to reduce runoff (Boardman, 2015; DEFRA, 2013; Ewan *et al.* 2013). The aim is to increase infiltration into the soil through soil structure maintenance, which as a result reduces runoff rates when compared to bare, poorly managed and compact soils (Environment Agency, 2012). Conversely, poor land management can lead to an increase in runoff which creates rills and gullies, thus causing enhanced solid erosion (Boardman, 2015). During high intensity rainfall events, this can exacerbate flooding causing muddy floods in settlements downstream (Boardman and Vandaele, 2010).

Although there is consensus around the advantages of land management practices in terms of runoff reduction, including a recommendation within the Pitt review (2008) which encourage land management practices that reduce runoff, the impact from such methods on peak flow reductions is argued across the literature (Burgess-Gamble *et al.* 2017; Hess *et al.* 2010; SEPA, 2016).

Research by the Environment Agency (2012) shows that soils which drain more freely and have a good soil structure typically have less than 2% runoff. Compacted soils on the other hand, can have up to 60% runoff. Similarly, Lunka and Patil (2016) suggested that through improved livestock and pasture management, infiltration and interception rates could be increased. JBA Consulting (2007) modelled a 120 km^2 catchment in Rippon, North Yorkshire with 10 subcatchment rainfall runoff models used. Land use scenarios were developed to represent changes to land management. These were centred on current land use including moorland, grassland and arable. Scenarios then represented “improved” or “degraded” soil conditions which reduced or increased runoff. Each scenario was assessed using summer and winter events with 10, 50 and 100 year return periods. Findings indicated that Ripon was likely to be susceptible to land management impacts. The worse scenario of degraded soils and increase moorland grip maintenance lead to increased peak flows by 20%. A less extensive change of 30% degraded soils lead to an increase in peak flows of 10% for smaller events and 3% for larger events.

However, there are studies suggesting that the FRM benefits gained from improved land management methods are limited. Hess *et al.* (2010) concluded within their study that runoff could be reduced through improved soil conditions for high frequency events, yet for lower frequency, high discharge events, the reduction in runoff is limited. It was also discussed by Pattison and Lane (2011), that although land management methods such as tree planting at Pontbren have been proven to increase soil hydraulic conductivity, upscaling such measures to the catchment scale may not have a significant impact on flood risk due to the chaotic hydrological processes within a catchment. Therefore, it was concluded that it was probable land use change should not be used as a FRM measure instead of more traditional approaches but should be used to compliment them.

3.4 Key natural flood management case studies

Within the Working with Natural Processes Evidence Base (Burgess-Gamble *et al.* 2017), 65 case studies were included within the review of the current evidence which assessed NFM as a FRM measure. From these, the key 4 within the UK are discussed in more detail.

3.4.1 Pontbren

The Pontbren project was initiated by farmers wishing to manage their land in a more sustainable way to increase long term economic output (Woodland Trust, 2013). As a result, Pontbren farmers increased woodland coverage from 1.5%-5%, fenced off areas of land from livestock and created vegetated shelter belts.

It is stressed within the Woodland Trust report (2013) that engagement with the farmers has been key to the success of the project. As landowners have been engaged with the project, a demonstration site for other landowners who wish to similarly develop NFM within their land has been created. Knowledge transfer and education can then be increased through interaction between a wider range of landowners. Furthermore, such an approach has highlighted barriers to be considered by project managers and land owners who wish to install NFM. Such barriers include current agrienvironment schemes not being flexible enough to support NFM and the need to balance the farm finances with NFM interventions on the land. Yet, it was noted that farmers reported increased farm productivity, which demonstrates that NFM methods can be beneficial for land owners and provide wider benefits beyond flood risk (Marshal *et al*. 2009).

Hydrological data at Pontbren was collected from an experimental slope. This limits its transferability to the catchment scale as plot scales were measured (Marshall *et al.* 2009). However, it was found through modelling that strategically placed shelter belts have the potential to reduce peak flows by up to 40% (Jackson *et al.* 2008). This is due to a reduction in soil compaction from livestock which in turn increased soil infiltration combined with an increase in saturated hydraulic connectivity created by tree roots within the soil (Wheater and Evans, 2009).

Overall, the Pontbren study concluded that NFM could mitigate against smaller probability events, but would have limited success during higher magnitude events (Marshall *et al.* 2009). The biggest limitation to the Pontbren project is that the project is set within a field scale and so upscaling to discuss catchment scale reductions in flood risk has its limitations (Pattison and Lane, 2011). Therefore, greater emphasis must be put on catchment scale interventions and monitoring within future projects.

3.4.2 Belford

The Belford project has been active since 2007 and has implemented soft engineering structures in the Belford Catchment (6 km^2), Northumberland (Nicholson *et al.*2012). As Belford has a small population, structural measures were not feasible under a cost-benefit ratio calculation. Therefore, a softer approach was taken which included installing NFM measures (Wilkinson, Quinn and Welton, 2010a). In Belford, properties are at-risk from more frequent return period events, so NFM has offered them a standard of protection. The structures implemented include bunds, storage ponds, LWD dams and riparian vegetation planting (SEPA, 2016).

Bunds were mainly located in wet areas of land as these are ideal locations to intercept flow paths, but also are the most unproductive areas of the farm (Wilkinson *et al.* 2010). However, when productive areas of land were used as attenuation features, they were designed to only fill during larger magnitude events so that land loss per year is limited. The bunds were designed to drain over a period of hours to maximise storage potential during multiple events and some were constructed from wood rather than soil after the landowner expressed that a loss of land was unfavourable (Wilkinson *et al.* 2010). It was also noted that using hand craft to construct the LWD dams reduced bureaucratic process and limited damage to the environment (Wilkinson *et al.* 2010). As such features are small, it was concluded that if one were to fail, the risk to the downstream settlement was low (Wilkinson, quin and Welton, 2010).

It has been concluded that the NFM measures installed at Belford have had some success in reducing flood risk. During the September 2008 event, it was reported that the runoff attenuation features (RAFs) filled and stored runoff water for up to 8 hours (Wilkinson, Quinn and Welton, 2010b). It was noted that it is important for the RAFs to drain down within a day to maximise storage capacity ready for the next event. However, Wilkinson, Quinn and Welton (2010b), state that the RAFs are not suited to higher flow events but can mitigate against events up to 1 in 25 annual probability and so they are limited as a FRM measure. Meanwhile, modelling approaches have concluded that a network of storage areas amounting to 19,250m^3 of storage can provide a 30% reduction in flood peak for a 1 in 12 year event (Quinn *et al.* 2013).

Although hydrological monitoring has been installed within the Belford catchment, it was set up as the NFM interventions were installed and so pre project hydrological data was not collected (Nicholson, 2013). Although storage potential was calculated and modelling has indicated success, findings are limited as evidence to demonstrate the impact on flood risk was not definitive (House of Commons environment, food and rural affairs committee, 2016; Wheeler Francis and George, 2016). It is therefore recommended that future projects implement a hydrological monitoring plan which includes pre and post project monitoring at the outset of the project. However, The Belford project offers empirical evidence to show how online NFM features store water during high flow events which has not been done within other research.

3.4.3 Pickering

The Pickering project, North Yorkshire, was set up as a response to the Pitt Review (2008) with an aim to deliver a FRM project which worked with natural processes (Nisbet *et al.* 2011a). The project aim was to construct 150 LWD dams (Thomas and Nisbet, 2012). Alongside this, 50 ha of woodland was planted within the Pickering Beck catchment. Part of the project was to engage with landowners and use the local community's knowledge to gain support and increase acceptance. This was successful, yet landowners were resistant due to the lack of funding offered to them.

LiDAR data was used to locate the site for the bunds in order to increase efficiency. LWD dams occur naturally every 7-10 channel width so this was used as a rough guide for the location of the constructed LWD dams. Over a longer term, the dams trapped more debris and the woodland delivered more LWD into the water course.

A lack of pre project monitoring for this project meant that data were limited. As a result, an upstream-downstream comparison was used instead (Nisbet *et al.* 2015). Nisbet *et al* (2011a), states that the woodland planted increased water storage by 14% indicating some success. The bund itself can store 120,000m^3 of water and reduces the annual risk of flooding from 12% to 4% (Nisbet *et al,* 2015). Yet it is argued by Wilkinson, Holstead and Hastings (2013) that such a feature does not fit within NFM categories. Cost benefit ratios of 1.3 were calculated for the large bund and 5.6 for woodland measures (Nisbet *et al.* 2015). In conclusion, although the bunds were more effective at storing water, both sets of measures complement each other (Nisbet *et al.* 2011a).

Although some success has been achieved, Nisbet *et al.* (2015) recognised some limitations to the project. During the project some LWD dams failed and so had to be removed, this highlights the importance of careful design and site selection to minimise the risk of failure. Another limitation suggested is that persuading land owners to plant woodland is still a difficult task. Thus, barriers to landowner uptake are still a significant hindrance to NFM implementation within the Pickering catchment. Finally, it is argued within the literature that the Pickering project is not a NFM project due to its highly engineered attenuation methods (Holstead and Hastings, 2013). Therefore caution should be taken when referring to the Pickering project as a NFM project to manage expectations.

3.4.4 Holnicote

Holnicote estate sits within Exmoor National Park and is owned by the National Trust (National Trust, 2015). The project consists of a range of NFM interventions including wetland creation, offline storage ponds, small bunds, afforestation and stopping LWD removal (National Trust, 2015). In addition, tenant farmers have been advised on best practice to manage grasslands, reduce compaction and increase soil infiltration (National Trust, 2015).

Hydrological monitoring to collect rainfall, stage and flow data was set up in 2010 to give a two years of baseline data (National Trust, 2015). This data was used to calibrate hydrological models and was also statistically tested to compare pre and post intervention hydrograph characteristics. The findings suggest that hydrograph analysis results were positive and show an effect on hydrograph delay, however it is noted that these effects were only slight (National Trust, 2015). Yet, it was concluded that the offline bunds helped to deliver a 10% reduction in flood peak during a December 2013 event and so some success was achieved (National Trust, 2015).

The project took an ecosystem services approach in order to maximise the wider benefits of the NFM interventions. This was concluded to improve biodiversity, soil management and water quality (National Trust, 2015). Furthermore, stakeholder engagement through a local project manager increased overall project success and engagement with the local community (National Trust, 2015). Therefore, thorough stakeholder engagement is a recommendation for future NFM projects.

Although success was documented, the project also identified barriers to NFM. The first was that some monitoring was set up in sub-optimal locations and so the monitoring network had to undergo some changes during the project. Another barrier identified was that although opportunity mapping took place, some of the interventions could not be realised as the land already had uses that would conflict with NFM (National trust, 2015). Thus, engagement with land tenants and a payment for ecosystem services approach was recommended (National Trust, 2015).

3.5 Attitudes towards NFM from at-risk communities

To date, few studies have researched the attitudes towards FRM of communities who have previously experienced a significant flood event. Furthermore, research has not been conducted to assess flood affected community attitudes towards NFM beyond anecdotal evidence. While some studies have been conducted which are applicable, many focus on other aspects of Integrated Flood Risk Management (IFRM) such as Blue Green Infrastructure (BGI) (Thorne *et al*. 2015) and a "room for the river" approach, which promotes the natural inundation of the floodplain (Groot, 2012; Everett *et al*. 2018). Due to the lack of studies, it is necessary to extend the review to community attitudes towards IFRM within this study.

The current lack of hydrological evidence has been recognised as a national issue for the wider uptake of NFM (Burgess-Gamble *et al*. 2017; Dixon *et al*. 2016; Environment Agency, 2017; Dadson *et al*. 2017). The lack of evidence to support NFM as a FRM measure influences public attitudes through the creation public uncertainty of NFM, and the benefits that it can achieve (Bracken et al. 2016). Unlike structural measures, NFM methods cannot be as easily quantified in terms of flood risk reduction and therefore results cannot be easily communicated to communities at-risk (Environment Agency, 2012; Collentine and Futter, 2016). To overcome this, it is suggested that more quantitative evidence needs to be gathered and effectively communicated with the public (Burgess-Gamble *et al*. 2017).

The consequences of a lack of community knowledge and understanding of IFRM methods are documented within the literature. Mehring *et al*. (2018) found that 95% of their surveyed community suggested local residents should be involved within FRM decision making. This highlights that at-risk communities wish to be involved within FRM projects. The respondents also stated that decision making process should include the use of lay knowledge gathered from the community. Ignoring such engagement could have severe negative impacts on the attitudes of the community and therefore the FRM project overall.

Waylen *et al.* (2017) found that practitioners within the statutory sector faced a barrier to NFM uptake if the public did not understand the benefits of NFM in terms of flood risk reduction. They wrote that practitioners of NFM felt that support for NFM was reduced and hard engineered structures were a preferred option of the community at-risk. Similarly, Thorne et al. (2015) found that practitioners in Portland cited public preference for hard engineering as a significant barrier to the implementation of BGI. Moreover, practitioners expressed that the lack of continued support from political leaders was a concern, as this may reduce in the context of climate change and in turn may lead to a change in public preference towards short term instant solutions. Everett *et al*. (2018) also discussed factors impacting on public acceptance of blue-green infrastructure in Oregon, USA. They found that acceptance was hindered by a lack of community knowledge of the installations. This caused residents to be cautious of the interventions and an opinion was cited that the government were being misleading with regards to BGI's impact on the local environment. The research discussed that effective communication may help to improve future acceptance of BGI features and the allocation of funds towards them. These examples of research support the argument that a lack of knowledge and/or a preference towards hard engineered structures by the public are barriers to the uptake of IFRM techniques.

Although the examples discussed focus on IFRM, the findings are applicable to NFM projects and so the knowledge of NFM by at-risk communities is an important consideration. Increasing knowledge can improve awareness of NFM which may help to improve community acceptance of NFM interventions (Everett et al 2018; Thieken *et al*. 2007). Increasing knowledge can additionally influence behaviour. For example, research by Maidl and Buckecker (2015) found that professional individuals with greater knowledge of flood risk were more likely to have installed property level resilience measures on their properties. This further demonstrates that knowledge influences the attitudes and behaviour of flood affected residents towards intervention, so it is vital that these factors are considered when NFM intervention is sought by practitioners.

Preference for structural measures by communities at-risk was discussed by Buchecker (2016). It was found that the public in two at-risk communities in Switzerland showed more support for structural measures but were still open to IFRM interventions. The study found that the negative emotional experience of flooding was a strong predictor for support for structural measures, meaning that those who have been previously flooded showed preference towards structural interventions. This variation in attitudes was discussed further by Fitton, Moncaster and Gurtherie (2015) who concluded that at-risk residents in a town in England focused on improvements to the quality of life, such as not being flooded, and that these participants did not consider other benefits beyond FRM. Residents who were considered not at-risk were found to focus more on aesthetics or economic gain of a potential FRM scheme. Therefore, the attitudes of the community can be influenced by both previous experience and the potential risk of future flooding.

Tunstall *et al*. (2000) identified that softer approaches, such as NFM, were seen to offer a lower standard of protection when compared to structural measures. This is still recognised by most relevant hydrological literature, as NFM is considered to be beneficial during lower magnitude events and may become overwhelmed during higher flows (Stratford *et al*. 2017; Bornschein and Pohl, 2017; Dadson *et al*. 2017; Pattison and Lane, 2017). Therefore, at-risk communities may show preference towards hard engineered solutions which offer a greater standard of protection.

However, community support for softer FRM methods has been documented by a few studies. Groot (2012) for example found that public perception of softer FRM methods in Europe was influenced by ideas of stewardship over the environment. Measures which promoted “room for the river” ideology were considered safe and natural, but dyke reinforcement was considered unnatural. The study concluded that two thirds of respondents found “room for the river” ideology good or very good, suggesting public support for such intervention.

For another type of softer FRM intervention, large wood introduction, Ruiz-Villanueva *et al*. (2018) found that communities which had been previously flooded in Spain regarded wood in rivers as unnatural and dangerous and so a negative attitude towards this type of intervention was observed. Interestingly, previous flood experience was not found to be the main factor influencing attitudes towards wood in streams. Social -cultural backgrounds were found to be the main influences on perception within the study, with educational background and number of visits to the river found to influence an individual’s perception of wood in rivers. Again, this research concluded that more public information was needed to influence perceptions of IFRM methods. As wood in streams is a recognised method of NFM, this research presents implications which could impact upon NFM projects within the UK.

Studies have found that acceptance of NFM increases when wider benefits beyond FRM are achieved, such as habitat creation, water quality improvement and carbon sequestration (Buchecker, Ogasa and Maidl, 2016). The appearance of a river has been found to be important to local communities and so improving the aesthetic value of a watercourse may help overall acceptance (Fitton, Moncaster and Gurtherie, 2015). Tunsall *et al*. (2000) suggested that the local community recognised that river restoration provided wider benefits beyond FRM and so it can be argued that promoting such benefits may influence on attitudes towards this type of NFM measure. However, the research also found that the initial disturbance of the river restoration was found to upset some residents, who thought it had negative impacts for wildlife. This highlights that communication with local residents is crucial if attitudes are to be influenced through the promotion of environmental gains. A lack of community engagement can lead to undesirable consequences if negative aspects, in this case initial disturbance, are not made transparent to the community.

When communicating with at-risk communities, expectation management has been said to be key for NFM project success (Tseng and Penning-Rowsell, 2012: Ball, 2008; Morris, Beedell and Hess, 2014; Thomas and Nisbet, 2016). Without expectation management in FRM, outcomes may be frustration, distrust and conflict during the process of design and implementation, as the potential benefits and outcomes of the project have not been made clear (Tseng and Penning-Rowsell, 2012). NFM should not be sold as the sole method of FRM for a community as expected impacts on FRM are expected to be lower than those of structural FRM intervention (Nesshover *et al*. 2017).

Studies such as Rouillard *et al*. (2015) state that stakeholder engagement through participatory partnerships can increase collaboration and therefore overall success. It has been found that if a pre-existing framework of stakeholder engagement exists, such as a local participatory flood action group, then stakeholder engagement is generally more successful (Challies *et al*. 2016). Yet at present, stakeholder engagement is limited within FRM and this leads to conflict, frustration and a possible widening of inequalities within communities (Begg *et al*. 2017). Mehring *et al*. (2018) stated that a failure to recognise the complex social dimensions may lead to negative engagement between practitioner and communities. Thus, understanding community attitudes towards NFM and the factors that influence them is crucial for future NFM projects.

The literature review highlights that an individual's personal experience is a factor which influences their attitude and acceptance of IFRM. Previous flood experience has been found to be a variable which impacts upon an individual's preferences of FRM. Respondents who have a previous experience of flooding are more likely to show preference towards hard engineered FRM whilst those who are not at-risk show a preference towards IFRM which offers aesthetical and environmental benefits. Such wider benefits should also be communicated clearly if attitudes towards IFRM are to be made more positive when softer engineered FRM interventions are sought for an at-risk community.

As Holstead *et* al. (2015) discuss that public perception is a barrier to landowner uptake, public attitudes towards NFM could influence the uptake of NFM by land managers. This in turn could create further barriers to uptake and implementation. Therefore, further research into factors which affect community attitudes towards NFM is required.

3.6 Barriers to Natural Flood Management

For analysis we conceptualise a catchment where NFM may be installed as a socio-economic system (SES). Within the framework, biophysical factors interact with social variables to create outcomes. The SES framework that we use in this research is adapted from the framework proposed by Ostrom (2009). This framework allows assessment of barriers to NFM from across the two systems and so has been applied to the literature review.

3.6.1 Governance system

At present, the EA have responsibility in England, over main rivers whilst the LLFA have responsibility over ordinary watercourses (Flood and Water Management Act, 2010). It has been identified that there is still a lack of clarity on where the responsibility for flood risk lies due to the complex structure between EA, LLFA, IDB and any other related bodies (National Audit Office, 2014). As NFM is ideally situated within the upper catchment, outside of settlements and so on ordinary watercourses, NFM will most often need to be implemented by the LLFA (House of Commons Environmental Audit Committee, 2016).

Conflict can be caused though the contesting interests of organisations. For example, the EA may be focusing on structural measures whilst the LLFA focus on floodplain economic development, which can mean that FRM is reverted back to flood defence (Huq and Stubbings, 2015). Meanwhile, as NFM is a relatively new method of FRM, a report by the House of Commons Environmental Audit Committee (2016) suggested that NFM was outside the skillset of the bodies who are tasked with implementing it. This could significantly hinder NFM projects and reduce the opportunities to expand the evidence base. Therefore, an increased level of knowledge surrounding the hydrological process of NFM will be needed by authorities and organisations who are tasked with implementation.

Previous research shows that a current lack of evidence, and the resultant uncertainty about NFM as a FRM measure, creates a significant barrier to uptake (Waylen *et* al. 2017; Rouillard *et al.* 2015; O' Donnell *et al.* 2017). Wilkinson *et al*. (2019) state that empirical evidence is needed to understand the effectiveness of individual NFM measures. However, there is currently a lack of monitoring of ongoing NFM projects which significantly limits the evidence base of NFM effectiveness (JBA consulting, 2015; DEFRA, 2013; POST, 2011). This may be due to the forward drive to implement projects, which limits the opportunity for pre project monitoring, but also due to monitoring not being built into funding bids (JBA consulting, 2015; POST, 2011). In contrast, the Pitt review (2008), states that monitoring opportunities are restricted due to organisations not agreeing on who is responsible to do the monitoring, both pre and post project. As catchments have a complex hydrological system, monitoring to gather pre and post NFM implementation data is vital for future evidence to be reliable and applicable (Barlow, Moore and Burgess-Gamble, 2014).

At the national scale there has been a lack of evidence being generated to support NFM as a FRM intervention (Archer, Bathurst and Newson, 2016; Bracken *et al.* 2016; Cook *et al.* 2016; Barlow, Moore and Burgess-Gamble, 2014). Figure 3.3 (from POST, 2011) demonstrates the uncertainty surrounding upper catchment measures which target the source of runoff. Therefore, NFM may not being implemented due to the uncertainty of its impact as a FRM measure to the downstream receptor. To gather actual evidence rather than perceived evidence, catchment experimentation is required (O' Connel *et al*. 2007).

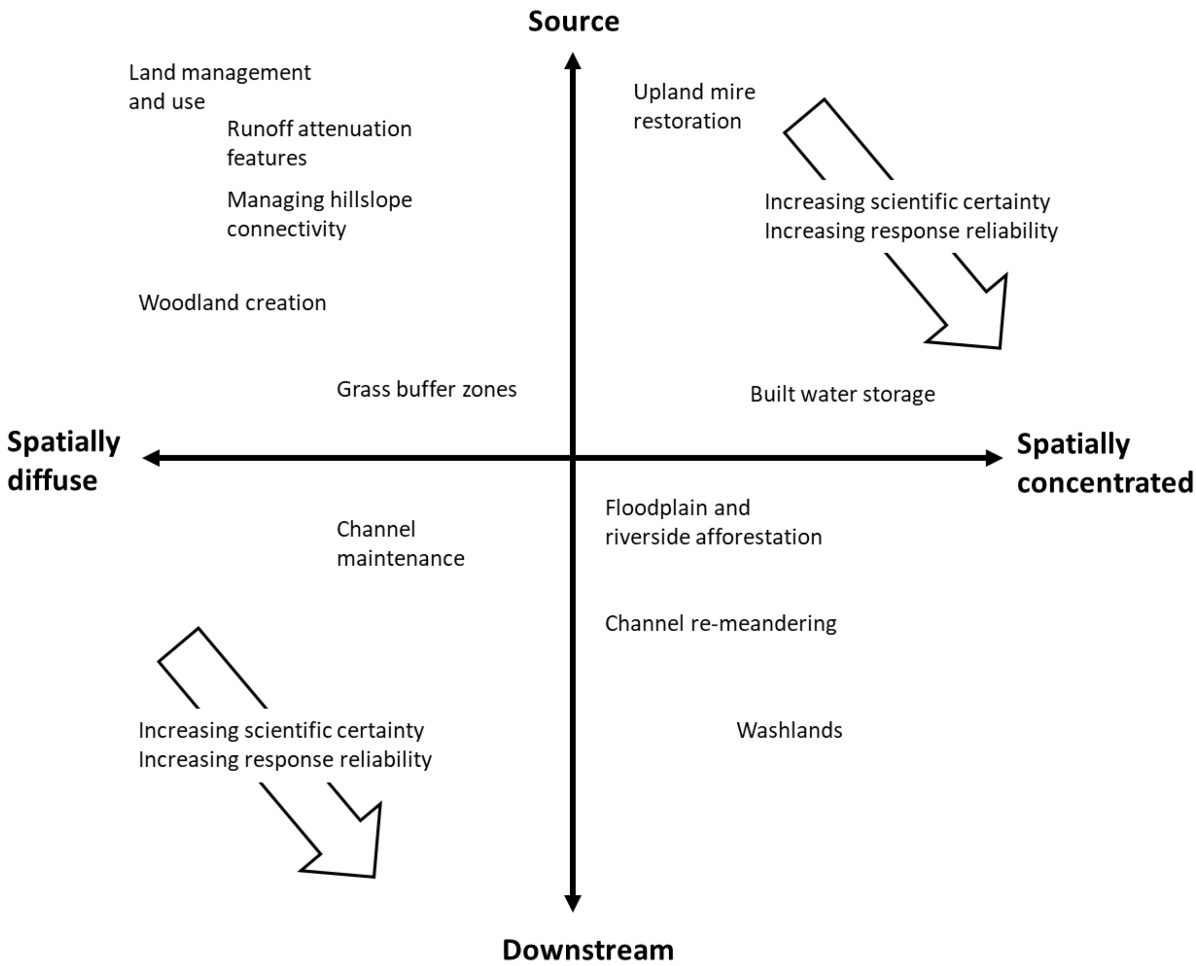

Figure 3.3 Catchment scale classification of NFM strategies (Post, 2011).

Although some studies have undertaken catchment experimentation to provide an evidence base for the effectiveness of NFM, such as the Belford, Pickering and Pontbren projects (Nicholson *et al*. 2012; Marshal *et al*. 2009; Nisbet *et al*. 2011), more studies are needed in order to discuss the long-term effects of NFM on flood risk. Pre-project monitoring is especially advised to collect data to analyse the timings of tributaries within the catchment. Not undertaking such research could cause unwanted issues such as higher peak flows if tributary flows become synchronised as a result of NFM interventions (Pattinson and Lane, 2012).

Additionally, there is a significant evidence gap to suggest whether catchment scale NFM will have any significant impact upon peak flows (Avery, 2012; Parrot *et al*. 2009; Cook *et al.* 2016). It is argued by Pattinson and Lane (2012) that, due to the complexity of catchments and their chaotic hydrological factors which can influence flows, upscaling from plot and field level NFM studies to catchment wide conclusions does not provide a reliable picture of how NFM is affecting the hydrograph. This argument is supported by Archer, Bathurst and Newson (2016) who suggest that NFM could have an impact on the local scale but due to the complexity of catchments and their hydrological systems, impacts seen at a catchment scale are likely to be limited. This further demonstrates that hydrological monitoring to gather pre and post NFM implementation data is vital to build up a long-term data record for future evidence to be reliable and applicable (Barlow, Moore and Burgess-Gamble, 2014).

A study by O'Donnell, Lamond and Thorne (2017) interviewed 19 professionals from within Newcastle to identify the barriers to uptake of blue green infrastructure (BGI). The study focuses on barriers situated within the local and regional scale of governance. It was found that securing funding was a barrier cited by more than half of the respondents, suggesting funding remains a significant barrier within the local and regional scale of governance. Similarly, Waylen *et al.* (2017) found that practitioners mentioned there was currently no direct funding mechanism for NFM and as other costs such as collecting data and modelling benefits also apply, gaining funding for NFM was considered a significant barrier to implementation.

Related to the lack of evidence, funding can be difficult to obtain for NFM schemes (Barlow, Moore and Burgess-Gamble, 2014). At present, the lack of evidence to support the effectiveness of NFM as a FRM measure creates difficulty in quantifying the amount of capital that can be protected by NFM methods (Environment Agency, 2012: Waylen *et al*. 2017; Wingfield *et al*. 2019). Current UK FRM policy requires a cost benefit ratio to be calculated in order to maximise outputs for inputs and to calculate the number of properties that will have a lower flood risk as a result of the FRM scheme. NFM benefits are more complex to calculate and are often not tangible. Therefore, when applying for funding for a FRM scheme, NFM is less likely to receive funding when compared to structural measures which allow for flood risk reduction to be calculated through modelling approaches (DEFRA, 2013). This leads to the NFM scheme not being implemented and so a feedback loop is created. Although the £15m of funding from DEFRA for NFM schemes may help to break this loop, the funding is not guaranteed past these projects and so funding in the future may be difficult to obtain.

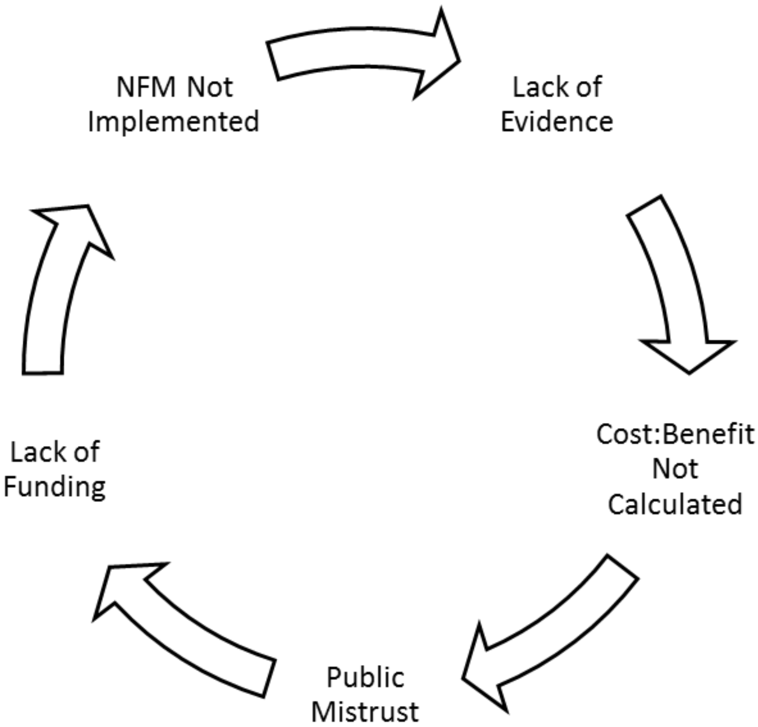

Figure 3.4 The feedback loop created by the barriers to natural flood management.

Wheeler, Francis and George (2016) state that nearly four times as much money is spent on land management that increases flood risk than is spent on land management that prevents flooding. Therefore, funding is not being effective channelled in a joined-up manner and presents a barrier within governance. This is expressed as a concern for some landowners who may lose out on agri-environment payments. For example, a bund installed on agricultural land may help to store runoff but may lead to a reduction in other subsidies (Holstead *et al.* 2014). Therefore, a landowner willing to install NFM may suffer an economic loss and so a barrier is presented.

At present, partnership funding is used within UK FRM to shift some FRM cost over to the public, thus creating a system that outputs both public and private benefits with regards to FRM (Greaves and Penning-Rowsell, 2016). This may in turn raise risk awareness and change behaviour as previous funding reduced risk perception due to the public expecting protection (Hartmann and Spit, 2016). Current partnership funding schemes have created a larger involvement of the community within many aspects of FRM including design, in turn wider success is achieved alongside a greater level of acceptance as more people can benefit from a scheme and have ownership over the outcomes (Greaves and Penning-Rowsell, 2016; Hartmann and Spit, 2016).

However, there are some arguments against partnership funding which stress future cation. One example of this is linked to social capacity. As partnership funding requires technical capabilities and a higher level of education in order to obtain funding there could be inequality as areas with a higher social capacity are able to obtain funding whilst areas of lower social capacity do not have the skill set or knowledge base to do so (England and Know, 2015). Due to this, partnership funding may cause communities with a lack of social capacity to become excluded from FRM.

Additionally, Thaler and Priest (2014) stated that flood action groups do not represent the full community as they are mainly made up of white, middle class professionals with expertise in planning and law. This point means that rather than elected politicians making decisions for citizens, some non-state actors receive greater power and become involved within decision making. These non-state actors may have their own agenda which may not reflect the needs of the public and could cause conflict whilst decreasing the effectiveness of decision making (Thaler and Levin-Keitel, 2016; Tseng and Penning-Rowsell, 2012). Overall it is suggested that partnership funding promotes wealthy rural areas with a high social capacity. Although partnership funding does increase stakeholder engagement, social capacity is needed for it to be successful (Thaler and Levin-Keitel, 2016).

A significant barrier to NFM uptake is a lack of consensus around the future maintenance of NFM measures and the lack of funding set aside for this (Ball, 2008). NFM like other FRM measures requires maintenance, including the desiltation of storage areas and repositioning of LWD dams. Underinvestment in maintenance is not economically sensible and can create further cost in the future (England and Know, 2015). A report by the House of Commons Environmental Audit Committee (2016) highlighted that the National Farmers Union acknowledged the importance of NFM but argued that the lack of maintenance of NFM measures could cause prolonged flooding unnecessarily, therefore uptake by landowners could be hindered. Thus, uncertainties around the future maintenance of NFM is a significant barrier to uptake.

At present, there is no clear policy on the liability for the maintenance of NFM measures. This means that although there are capital monies available for NFM, funding for maintenance is often overlooked (Post, 2011). Without future maintenance, NFM could become less efficient though sedimentation and may increase risk in some areas if measures such as LWD dams or bunds were to fail. Thus, a barrier is created as not only are landowners discouraged by the lack of support for maintenance, but also the measures themselves become a less efficient method of FRM over time which reduces their viability.

3.6.2 Actor based barriers

A significant barrier to the implementation of NFM is a lack of landowner uptake of interventions (Posthumus *et al*. 2008; Holstead *et al*. 2015). Landowners as actors, are the key decision maker, who decide whether they wish to implement NFM. Whilst not all landowners are farmers, and so the two may have different barriers to uptake, ultimately the decision to implement NFM falls with the owner of the land. Little research has currently been conducted on the willingness of landowners to uptake environmental improvement measures, including NFM (Mills *et al.* 2017). It is therefore important to identify and assess such barriers to this group of actors in detail and to assess if current practice considers such barriers.

Barriers to landowners are complex and as shown in Figure 3.5**,** cross between to landowner engagement, willingness to adopt and ability to adopt (Mills *et al.* 2017). This means that whilst some landowners may be willing to install NFM, their capacity to do so is limited due to factors such as farm finances or the biophysical aspects of their land. On the other hand, some landowners may be able to adopt as the opportunity and capacity to do so is present but factors influencing their attitude towards NFM, means their willingness to install NFM is low.

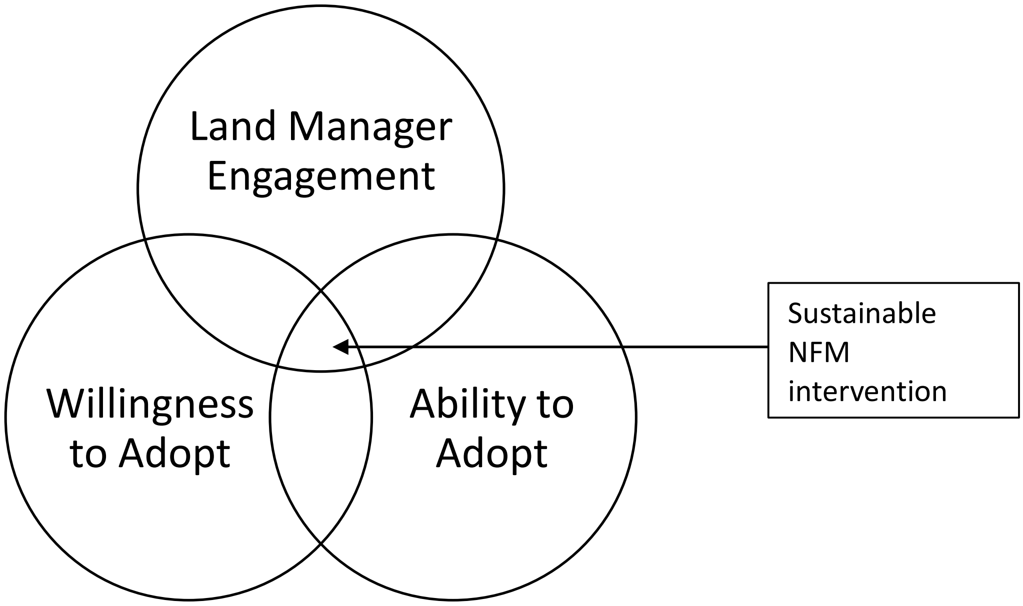

Figure 3.5 Factors influencing land manager decision making. Adapted from Mills et al. (2017).

Willingness to adopt may be influenced by a lack of knowledge of NFM by landowners. Mills *et al.* (2017) give an example where an interviewed farmer was not willing to uptake environmental measures as they did not see any features on their land which would be suitable, despite their being opportunity to do so. This highlights that willingness to adopt has been influenced by a lack of knowledge and so increased landowner engagement is needed.

The land use can impact upon the perception of NFM by landowners. Short Gianotti, Warner, and Milman (2018) used a postal survey to analyse the perceptions of FRM by rural landowners in the USA. It was found that landowners owning land with an agricultural land use were concerned about economic loss and damages caused by flooding. On the other hand, residential landowners were more concerned about aesthetics. Therefore it is important to consider the use of the land when planning a NFM project as some land owners may be more willing to install NFM if they have land, or parts of land, which is not within agricultural production.

A barrier which can be linked back to the lack of evidence to support NFM is that the uncertainty over the effectiveness of NFM causes landowner uncertainty over the impacts of potential NFM implementation. As a result, landowners are not willing to give up land for interventions which may offer no benefit to the downstream communities (Bracken *et al*. 2016).

A study by Holstead *et al*. (2015) used semi-structured interviews with 15 farmers in Scotland to discuss the potential barriers to NFM uptake from their viewpoint. Discussion suggested that there are six criteria which affect land owner uptake: economics, availability of advice and support, public perception, joined up policy, catchment planning and traditions. It was found that the biggest individual barrier (64% of respondents agreed) was the lack of support and information provided to install NFM. They recommended that clearer information needs to be provided with land owners having a personal advisor who is trusted. Likewise, an appointed advisor could help with paperwork generated by multiple policies and consents required before implementing NFM.

It was also said By Holstead *et al*. (2015) that 53% of farmers who had not installed NFM said their land was too valuable and 38% stated that there was insufficient funding. It was similarly found by Rouillard *et al*. (2015) that landowners in Scotland and England were not willing to give up productive land for FRM. The study found that farm economics was a significant barrier to catchment wide FRM as a loss of agricultural land may incur losses of agricultural subsidies which require land to be in productive agricultural practices. This highlights that without sufficient financial support, land owner uptake will be low.

Mccarthy *et al*. (2018) interviewed key stakeholders involved with the use of financial mechanisms which are used to gain rights to flood private land. Findings suggest single payments to landowners are preferred as inundation periods and frequencies can be uncertain. Compulsory purchase is an option to the Environment Agency, but this is not preferred as it brings with it organisational responsibility. The study highlights that a key aspect of financial compensation is to make clear to landowners what is being offered for the specified outcomes. Moreover, maintenance costs should be considered within the compensation. A report by the House of Commons Environmental Audit Committee (2016) stated that the National Farmers Union acknowledged the importance of NFM but argued that lack of maintenance interventions could cause prolonged flooding unnecessarily. Both studies suggest that the current lack of governance over future maintenance of NFM is a barrier. This also demonstrates that NFM barriers can be complex and cross multiple stakeholders and jurisdictions. Without policy, resources and funding in place, practitioners are unable to offer landowners future maintenance options which will hinder landowner uptake.

Another barrier to NFM is landowner consideration of public perceptions of the farm (Holstead *et al.* 2015). Farmers felt that they were being blamed for flooding whilst other factors were also to blame. This reduced landowner support for implementing NFM when it was perceived that issues such as land still being developed on the flood plain were not being addressed and so flooding would happen regardless. Landowners felt it was beyond their duty to retain water on their land without a more holistic approach to FRM being taken (Posthumus *et al*. 2008).

Finally, traditions of landowners create a barrier to NFM uptake. Farmers were historically paid to drain land with ditches and land drains to maximise production (Iacob *et al.* 2014; Wheater and Evans, 2009). Thus, the reversal of this would underpin the legacy left by ancestors of the farm and move a farmer away from their role as a food producer towards a land manager (Holstead *et al.* 2015). Furthermore, landowner attitudes towards the landscape amenities themselves can create a barrier as landowners want ditches to be clear and to drain the land effectively, thus engraving a culture of drainage (Rouillard *et al.* 2015).

With reference to practitioners of NFM as actors, barriers to NFM can exist within an institutional setting. A study by Waylen *et al*. (2017) interviewed 18 practitioners within FRM institutions in Scotland to discuss the barriers to implementation of NFM. The study identified three key themes surrounding barriers to NFM from within institutions: challenges in using evidence and handling uncertainty, difficulties in allocating resources and complexities of coordination and communication. Barriers surrounding evidence and uncertainty have been discussed above and overlap within the governance category. Barriers regarding coordination and communication are discussed later within the interactions category. However, some of the barriers identified within the research are actor specific.

For example, practitioners felt that it would be difficult to change public and landowner attitudes without scientific evidence which supports the use of NFM (Waylen *et al.* 2017; Rouillard *et al.* 2015). Therefore, practitioners did not see NFM as a method that could be widely implemented. Furthermore, due to the uncertainty surrounding NFM, practitioners suggested that the fear of unexpected consequences was a current barrier to NFM uptake by them (Waylen *et al.* 2017). This was particularly significant in the event of LWD dams moving and blocking structures such as bridges or culverts.

At present, FRM practitioners in Scotland include a large proportion of engineering based professionals (Waylen *et al*. 2017). This can create resistance to change, especially for practitioners with a lack of knowledge of NFM approaches (Waylen *et al*. 2017; Cook *et al*. 2016; O' Donnell *et al*. 2017). Therefore, there is a reluctance to change towards softer engineered approaches within FRM, especially for employees who have a lack knowledge of NFM methods and what they aim to achieve. This was similarly found by O' Donnell *et al.* (2017) as practitioners' reluctance to change to new and novel FRM practices was cited as a barrier to blue green infrastructure. Therefore, there may be an initial inertia towards change if this barrier is not overcome though education and knowledge transfer.

A barrier to the public as actors is that a mistrust of NFM is founded as unlike a structural measure, NFM methods cannot be as easily quantified in terms of flood risk reduction (Environment Agency, 2012; Collentine and Futter, 2016). To overcome this, quantitative evidence needs to be provided which gives evidence for the effectiveness of NFM as a flood risk intervention (Avery, 2012). Project managers should also be more open and transparent with stakeholders and where possible involve them in order to prevent misinterpretation of the implementation process (Howgate and Kenyon, 2009).

Another barrier related to public acceptance is that NFM interventions are often located outside of settlements which causes a spatial disconnect between where the interventions are and where the benefits are realised (Collentine and Futter, 2016). Unlike a structural measure, the benefits of a NFM intervention cannot be immediately seen by the public. As these benefits are not tangible, public support may be reduced as they cannot see how NFM will reduce their flood risk. It is recommended that greater education and engagement with the public may help to overcome this barrier (Environment Agency, 2012). However, public expectations present another barrier to NFM uptake if not managed during such communication (Chappell, 2006).

Social capacity is the ability to make decisions and act accordingly following the occurrence or an external stressor (Kuhlicke *et al.* 2011). If social capacity within a given area is low, the public are less likely to know where to obtain information and who best to contact to gain knowledge. Therefore, low social capacity is a barrier to NFM (Thaler and Levin-keitel, 2015). If social capacity within a community is low, stakeholders will be less likely to use the power provided to them within stakeholder engagement opportunities but furthermore, their capacity to cope with flood events decreases (Green and Penning-Rowsell, 2010).

Studies have suggested that at present social capacity influences the engagement of stakeholders within FRM projects and therefore the success of FRM projects (Thaler and Levin-Keitel, 2016). Furthermore, social capacity differences may be creating spatial inequality within FRM due to the nature of partnership funding (Thaler and Priest, 2014). The partnership funding approach allows for funding to be obtained from both government and local sources which in turn allows for increased stakeholder engagement within the FRM process (DEFRA, 2011).Yet, areas with a lower social capacity have a lower capacity to organise and obtain such funding causing them to receive less FRM opportunities (Thaler and Priest, 2014; England and Know, 2015). This creates further barriers as opportunities to implement NFM are being missed in areas of low social capacity.

3.6.3 Resource system and units

Biophysical land characteristics are documented by Mills *et* al. (2017) as a current barrier to the uptake of environmental measures by farmers. NFM currently has biophysical barriers restricting its implementation which may reduce overall uptake of interventions. Installing an appropriate NFM intervention depends on the characteristics of a watercourse and, just as importantly, its surrounding catchment (Avery, 2012). For example, the watercourse gradient, catchment soil type, elevation and land use type are examples of catchment parameters that must be assessed before NFM implementation. If the watercourse gradient is too steep, interventions such as LWD dams may not be appropriate as scour may be exacerbated within the streambed (Thomas and Nisbet, 2012). Additionally, if the land use surrounding the watercourse is residential or supports high value crops, NFM will be faced with barriers due to a significant loss of resource units.

If structural measures are implemented instead of NFM interventions, opportunities to implement NFM may become limited due to the infrastructure created (O'Donnell *et al.* 2017). In turn, floodplain development occurs as the area is perceived to have less risk from flooding. This prevents NFM methods such as floodplain storage areas, tree planting and bunding, as the spatial requirements are not present (Huq and Stubbings, 2015).

3.6.4 Interactions

In Scotland, Waylen *et al.* (2017) identified three key themes surrounding barriers to NFM from within institutions. They were: challenges in using evidence and handling uncertainty; difficulties in allocating resources; and complexities of coordination and communication. It was found that a lack of communication, both within institutions as well as between organisations, causes barriers to NFM uptake (Waylen *et al*. 2017). Without knowledge sharing and communication between organisations and institutions, NFM uptake will be hindered. This is especially important within cross-boundary catchments (Rouillard *et al*. 2015). These may cross the borders of a local authority, or at a larger scale, national borders. It can be difficult to determine where one jurisdiction ends and another begins, especially in the case of ordinary watercourse and main river responsibilities (Bracken *et al*. 2016). Therefore, due to the lack of communication between responsible organisations from both sides of the boundary, a barrier to NFM implementation is presented in that a project may fail due to the lack of communication and coordination.

The study by Waylen *et al.* (2017) found that interactions between organisations is currently limited and so barriers remain to NFM projects. As there could be mismatches between organisations in terms of funding resources, timescales and intended outcomes (Environment Agency, 2017), it is imperative that dialog takes place in the early stages of NFM projects in order to discuss such differences and set out a collaborative outcome (Waylen *et al.* 2017).

Waylen *et al.* (2017) also discussed that interactions between practitioners within the same organisation is a barrier to uptake. This may be due to different teams having different priorities within the organisation and so are not able to assist with NFM projects. Yet, as NFM requires interdisciplinary knowledge from fluvial geomorphologists, hydrologists, social scientist and ecologists (to name a few), it is essential that interaction within organisations takes place to overcome this barrier.

It is recognised that there is a greater need for stakeholder engagement, with specific emphasis on interactions between practitioners and landowners, if barriers to the uptake of NFM are to be overcome (O'Donnell, Lamond and Thorne, 2017; Cornell, 2005). Stakeholder engagement with landowners as an interaction raises awareness of NFM and can be used to overcome cultural barriers through awareness raising and education (DEFRA, 2013).

Another barrier to NFM implementation is negative interactions between the public and landowners (Holstead *et al*. 2015). Farmers felt that they were being blamed for flooding which reduced landowner support for implementing NFM. Within the Holstead et al. (2015) study, catchment planning was suggested as an emergent theme. Landowners were concerned that NFM would allow further development on the floodplain and 38% of respondents stated that they were more likely to implement NFM if it was part of an integrated, catchment wide plan, rather than just an isolated effort on their behalf. Therefore, without proper catchment planning as an interaction between governance, actors and the resource system, landowners are likely to not be as accepting of NFM as a viable FRM intervention.

Decision making within FRM using a top down structure is easy to manage but can often result in sub-optimal decision making and conflict (Cornell, 2006; Tseng and Penning-Rowsell, 2012). Stakeholder engagement as an interaction can give greater success over decision making within FRM, as stakeholders are given a sense of ownership over the processes and outcomes of a scheme (Thaler and Levin- Keitel, 2016; Tseng, c. and Penning-Rowsell, 2012). This may in turn increase a landowner's willingness to adopt, but also builds their capacity and ability to adopt. For example, Mills *et al.* (2017) suggest that involving landowners within academic research increases their willingness to adopt environmental measures. Additionally, it is argued by Stoate *et al.* (2019) that involving landowners within participatory research can increase the landowner's positive engagement with the project. As many organisations can be involved within an NFM project, especially when aims other than FRM exist, conflict can be reduced between parties and project acceptance increased through interactions between these stakeholders (Cornell, 2006; Waylen *et al.* 2017). Moreover, it is becoming more widely accepted that through stakeholder engagement, local knowledge can be utilised to identify flow paths and validate models (Environment Agency, 2017; Hankin *et al.* 2016; Mehring *et al.* 2018). This is especially applicable to landowners who have significant knowledge of flow paths across their land.

Stakeholder engagement with landowners can be used to overcome cultural barriers through awareness raising and education (DEFRA, 2013; Challies *et al.* 2016; Posthumus *et al.* 2008). As NFM requires multiple landowners to be cooperative in order to create enough storage to impact on peak flows, it is vital that effective methods are used to improve the knowledge, attitudes and behaviour towards NFM by landowners. Therefore, landowners need to be involved from the beginning of NFM projects to improve attitudes. It is recommended that such engagement should be combined with creating wider benefits beyond FRM in order to create a more sustainable approach and further develop relationships with landowners (Holstead *et al.* 2015).

Although stakeholder engagement with landowners is beneficial for FRM, a barrier can be a lack of stakeholder analysis from the outset of the project causing some important groups or individuals to be left out (Tseng and Penning-Rowsell, 2012; Thaler and Levin- Keitel, 2016). To overcome this a complete stakeholder analysis should be undertaken before a project commences, to identify all landowners and other relevant stakeholders within the catchment.

A possible method to overcome barriers to landowner uptake, which falls within the interaction's category, is through landowner site visit to NFM demonstration sites. NFM demonstration sites offer the opportunity for landowners to visit a completed project with interventions in place which may be applicable to their catchment. This is mentioned as a method to increase uptake on agricultural land within several studies (Posthumus *et al.* 2008*;* Mccarthy *et* al 2018; Holstead, Colley and Waylen, 2016; Wilkinson, Quinn and Welton, 2010b) and suggested as beneficial by the Environment Agency NFM Toolbox (2017). As succession of the farm was highlighted within the Rouillard *et al.* (2015) study as an important factor which could influence landowner uptake of NFM, demonstration sites need to show that FRM can fit within the farmed landscape and be economically viable to the farm business for future generations.

Literature suggests that this can increase knowledge of NFM and give the landowners an opportunity to see the interventions themselves and ask further questions (SNIFFER, 2011; Wilkinson, Quinn and Welton, 2008; RPA, RHDHV and Allathan Associates, 2015). Using this method can allow for landowners to participate within the NFM implementation process and increase landowner knowledge (Short *et al*. 2018). However, no studies to date have documented the level of success that this method can achieve. While anecdotal evidence suggests that uptake may be increased by such methods, more research is required to understand if this method can overcome the complex barriers to landowners identified within this literature review.

3.7 Research Gaps

The first research gap identified relates to question 1 of this thesis, as it has been found that more quantitative evidence is needed to demonstrate that NFM can be an effective catchment scale FRM solution (Burgess-Gamble *et* al. 2017; Avery, 2012). At present, there are few studies that use a catchment-wide approach to discuss the effectiveness of NFM measures (Huq and Stubbings, 2015). Due to the complexity of catchments and the variation in characteristics between them, this will be a difficult objective to reach without appropriate funding and research inputs (Parrot *et al*. 2009; Pattinson and Lane, 2011). Research is needed to quantify the benefits of NFM measures in order to calculate a cost-benefit ratio (Environment Agency, 2012). However, empirical data are at present limited and so NFM projects should have sufficient pre and post implementation monitoring plans in order to support the evidence base (Burgess-Gamble *et* al. 2017; Barlow, Moore and Burgess-Gamble, 2014).

A second research gap is that although some studies have been conducted to assess knowledge of public attitudes towards NFM (Buchecker, Ogasa and Maidl, 2015; Howgate and Kenyon, 2009; Turnstall *et al*. 2000), these studies are often limited to one type of intervention such as river restoration, or more general integrated approaches to FRM. This research gap relates to question 2 as research has not been conducted to assess at-risk community knowledge of NFM and the implications that this may have on favourability. As mentioned previously, stakeholder engagement is an important element of NFM intervention and so community knowledge and favourability is an important consideration within NFM projects. Thus, research is required to assess current knowledge and the implications that this may have on FRM preferences.

A third research gap is that little research has been undertaken to understand the cultural and institutional barriers to NFM involving wider stakeholders which includes landowners and practitioners of FRM (Barlow, Moore and Burgess-Gamble, 2014). There are a lack of studies which analyse landowner attitudes to NFM, with only two studies so far being applicable (Holstead *et al.* 2015; Rouillard *et al.* 2015) and so this research gap will be a focus of question 3. More research is needed to identify the barriers to uptake as NFM is ideally located in the upper catchment on agricultural land. Without support from landowners, opportunities for NFM implementation will be lost.

Related to question 4, a research gap identified is that no study to date has attempted to measure the impact NFM demonstration sites on landowner knowledge, attitudes and behaviour. As this method is mentioned in the Environment Agency NFM toolbox (2017) and anecdotal evidence suggests success, it is imperative that research measures the methods ability to increase knowledge and change attitudes and behaviour towards NFM. This will be an important process in overcoming the barriers to landowner uptake.

Moreover, research is needed on how participatory catchment partnerships influence catchment FRM with specific reference to NFM (Rouillard *et al*. 2015). One approach to address this is to implement a NFM scheme within an integrated setting, which involves stakeholders at the earliest possible stage. This may increase the acceptance of NFM implementation though allowing a sense of ownership to develop whilst additionally providing data on stakeholder perceptions to NFM.

3.8 Summary

This review has discussed NFM interventions which have been documented within the literature, specifically focusing on how they have been designed and installed alongside findings related to their impact on flood risk. Current NFM experimental study sites have been assessed to identify successes and failures recognised during the project. This has been useful for intervention design and experimental design considerations within this research.

Flood risk within the UK is set to increase in the future and so integrated FRM measures at the catchment scale, including NFM, are required (Thorne, 2014). Individual NFM interventions and previous projects demonstrate some degree of success in reducing flood risk. Yet, these reductions are likely to be limited (National Trust, 2015; Wilkinson, Quinn and Welton, 2010a; Archer, Bathurst and Newson, 2016).

There is a currently lack of evidence to support NFM uptake (Hess *et al.* 2010; DEFRA, 2013). Through the lack of evidence, it is difficult to quantify any reductions in flood risk as a result of NFM implementation and so funding becomes limited (Barlow, Moore and Burgess-Gamble, 2014). Therefore, public favourability towards NFM may be hindered. Additionally, landowners become sceptical about any FRM gains that can be achieved through NFM due to the lack of evidence to show how NFM on their land will benefit the downstream community.

Research into public attitudes towards NFM has been found to be limited within this literature review. Findings within studies looking at public attitudes towards IFRM give mixed results. On one had Buchecker (2016) stated that the at-risk communities within their study showed preference towards structural FRM. This may be due to the at-risk community focusing more on improvement to their quality of life (Fitton, Moncaster and Gurtherie, 2015). However, Groot (2012) stated that public support for IFRM was found within their research. The literature findings have suggested that attitudes towards IFRM may be influenced more by personal experience as opposed to other respondent demographics.

Practitioners have been found to face barriers within the governance system such as the aforementioned evidence gap, interactions between practitioners and interactions with landowners. Landowners on the other hand have a significant number of barriers to uptake within the actor category as they are the main actors who choose if NFM is to be implemented on their land. Such barriers include cultural barriers, such as the engraved drainage culture, and a lack of knowledge of NFM. However, a significant barrier is the economics of the farm as economic losses will not be tolerated by landowners without proper recompense (Holstead *et al.* 2015: Rouillard *et al.* 2015). As the farm is first and foremost a business, NFM project planners need to be considerate of this. Additionally, a long history of ancestry influences including draining the land has engraved a drainage culture within the current farming community (Holstead *et al.* 2015; Rouillard *et al.* 2015).

Stakeholder engagement with all relevant stakeholders has been highlighted as important and is essential for success in future NFM projects (DEFRA, 2013). This not only increase knowledge transfer and give a sense of ownership, but also fosters relationships with farmers so that opportunities for NFM can be realised (Thaler and Levin-Keitel, 2016; Holstead *et al.* 2014). It can also increase collaboration and positive interactions between organisations and has been shown to be beneficial to projects which have a catchment wide focus (Rouillard *et al.* 2015).

Finally, as previous research into the barriers of NFM has taken a reductionist approach focusing on one or two stakeholders within the system, a holistic study is needed which demonstrates the barriers to NFM implementation across a range of stakeholders. This needs to be conducted across all levels of governance and include all actors within the system. In order to achieve this, interdisciplinary research is needed to bring together the physical, hydrological and socioeconomic challenges. Such an approach would allow for a more conclusive and in depth analysis to the current barriers to wider NFM uptake.

The next chapter will explain the study site in which this research is based.

4. Study site

4.1 Rationale for study site selection

Due to the interdisciplinary approach taken within the research, each key question set out within Chapter 1 requires different methods in order to achieve its objectives. For key question 1 a site is required where NFM can be installed and hydrologically monitored within the upper reaches of a catchment. For key question 2, the site requires an at-risk community which has previously experienced flooding. Key question 3 requires a national scale site in order to assess the barriers to practitioners, so England and Scotland were chosen. However, to assess the barriers to land managers, a smaller site which has a history of flooding is used. Key question 4, although linked to the data collected during the objectives of key question 3, requires a site with NFM present. As Nottingham Trent University own a proportion of the catchment above Southwell, NFM can more easily be installed. The catchment itself had not had NFM interventions installed previously, and so is a site where research around the effectiveness of NFM would be beneficial. Therefore, as Southwell a town which has experience recent flooding and would be applicable for NFM intervention in the upper catchment, the site can be used to reach the objectives of all four key questions. This research and study site is case study 25 within the WWNP evidence base (Burgess-Gamble *et al.* 2017)

The town of Southwell (Nottinghamshire, UK) is situated within a rural- urban catchment and has experienced recent flooding events in both 2007 and 2013. It is estimated that 235 properties are at-risk during a 0.1% flood event, 118 from within the Potwell Dyke catchment and 117 within the Halam Hill catchment towards the North of the town (URS, 2015). A voluntary flood action group has been established following the later event (Southwell Flood Forum). Therefore, the catchment offers an excellent opportunity to work with local stakeholders within FRM such as the LLFA (Nottinghamshire county Council), flood forums, land managers, residents and the Environment Agency whilst installing NFM interventions.

The town has two watercourses which have caused flooding previously: the River Greet and the Potwell Dyke (Figure 4.1). The River Greet is a main river flowing from the North West to the South East of the town whilst the Potwell Dyke, which is an ordinary watercourse and a tributary of the Greet, flows from the South West towards the North East, passing directly through the centre of Southwell. As the Potwell Dyke was the main source of flooding during both of the recent flood events, this research focuses on the Potwell Dyke catchment.

Following the URS report (2015) planning has been ongoing for engineered FRM within the town, at the time of writing (2019) structural measures have not been implemented. This includes storage areas and hard engineered structures alongside property level protection. However, at the time of writing, these plans are in the early stages of design. The Southwell Flood Forum has been influential in the design of this scheme, with a technical subgroup set up in order to efficiently pass local knowledge onto the consultants tasked with design.

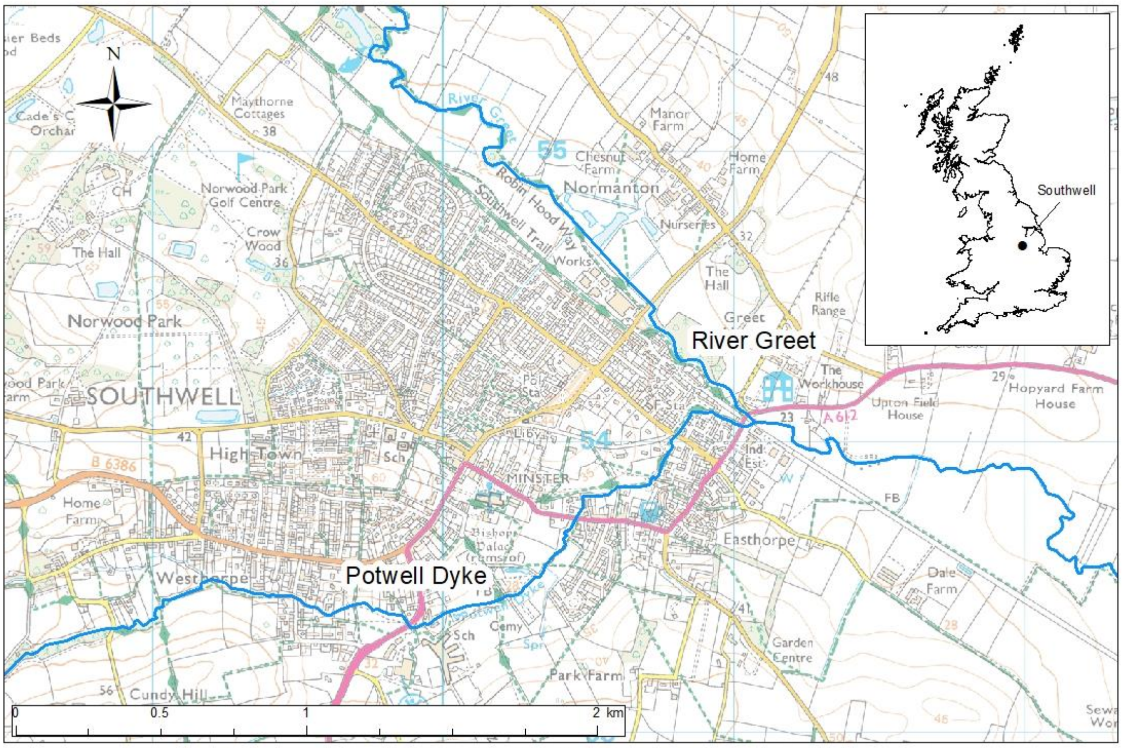

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Figure 4.1 Watercourses within Southwell, UK.

4.2 Previous flooding

Southwell has a history of flooding, with events documented in the 1950s, 1930s and 1922 (URS, 2015). Additionally, a high magnitude, low frequency historic flood event was documented on August 20th, 1857 in the Nottinghamshire Guardian, during which a fatality and extensive flooding within the town was recorded.

On June 25th 2007 prolonged heavy rainfall caused flooding within the town. Following this, a questionnaire was sent to the residents of Southwell as part of the River Greet Strategic Flood Risk Mapping (SFRM) commission (URS, 2015). The results concluded that, during the 2007 event, significant fluvial flooding occurred along the Potwell Dyke but also pluvial flooding was observed (URS, 2015). The return period for this event was calculated at 150-200 years (0.67% AEP to a 0.5% AEP) (URS, 2015). More recently, on July 23rd 2013 Southwell experienced a high magnitude, low frequency flood event caused by high intensity rainfall as a result of a convective storm system over Nottinghamshire (Suri and Page, 2014). Rainfall readings from the Nottingham Trent University Casella tipping bucket rain gauge (located within the Brackenhurst camps on the outskirts of Southwell), recorded 107.6mm in 75 minutes, intensity was such that 102.8mm of this fell within an hour (Figure 4.2). The event return period is calculated at 2953.8 using FEH 2013 60 min return period (using annual maximum series). However, this value is subject to inaccuracy due to the magnitude of the event rainfall.

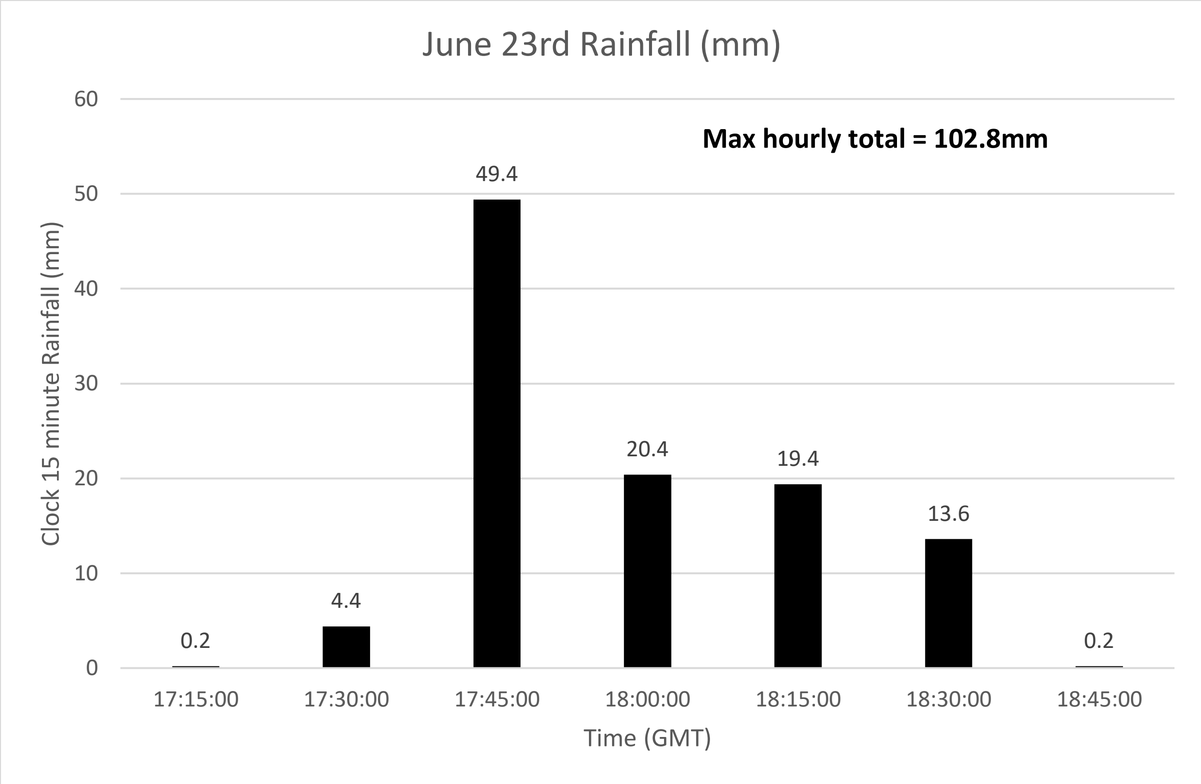

Figure 4.2 Clock 15 minute rainfall recorded by the Ott Brackenhurst rain gauge during the 23rd June 2013 event. (Data from Nottingham Trent University).

As a result of the high intensity rainfall, surface water flash floods and fluvial flooding occurred which was exacerbated by upper catchment runoff (URS, 2015). Consequently, the LLFA recorded that 424 properties experienced exterior flooding, with 253 of those also experiencing interior flooding (URS, 2015). Meanwhile, transport links were cut off as main roads into Southwell were inundated. The Nottingham Road culvert which an ordinary watercourse flows through collapsed, causing significant damage to the road itself.

Figure 4.3 Fluvial flooding at Nottingham Road, Southwell, during the 2013 event. Image: www.southwellfloodforum.org.uk

Figure 4.4 Pluvial flooding at Lower Kirklington Road, Southwell, during the 2013 event. Image: www.southwellfloodforum.org.uk

4.3 Catchment description

4.3.1 Size and topography

As the Potwell Dyke is the main cause of flooding for the town of Southwell, this thesis focuses on its catchment rather than that of the Greet. In the upper reaches of the catchment, the watercourses feature deep incised channels with woody banks which are locally termed as Dumbles (figure 4.5). This continues until roughly the edge of the town where channel size is reduced. The Potwell Dyke catchment is around 5.7km^2 and features steep topography rising from 104m in the south west and falling to 23m in the north east (Figure 4.6). The catchment itself has three sub-catchments within it: the Westhorpe Intake (1.17km^2), Parkland Dumble (0.41km^2) and Springfield Dumble (0.65km^2) (Figure 4.7).

Figure 4.5 The upper reach of the Potwell Dyke (Dumble).

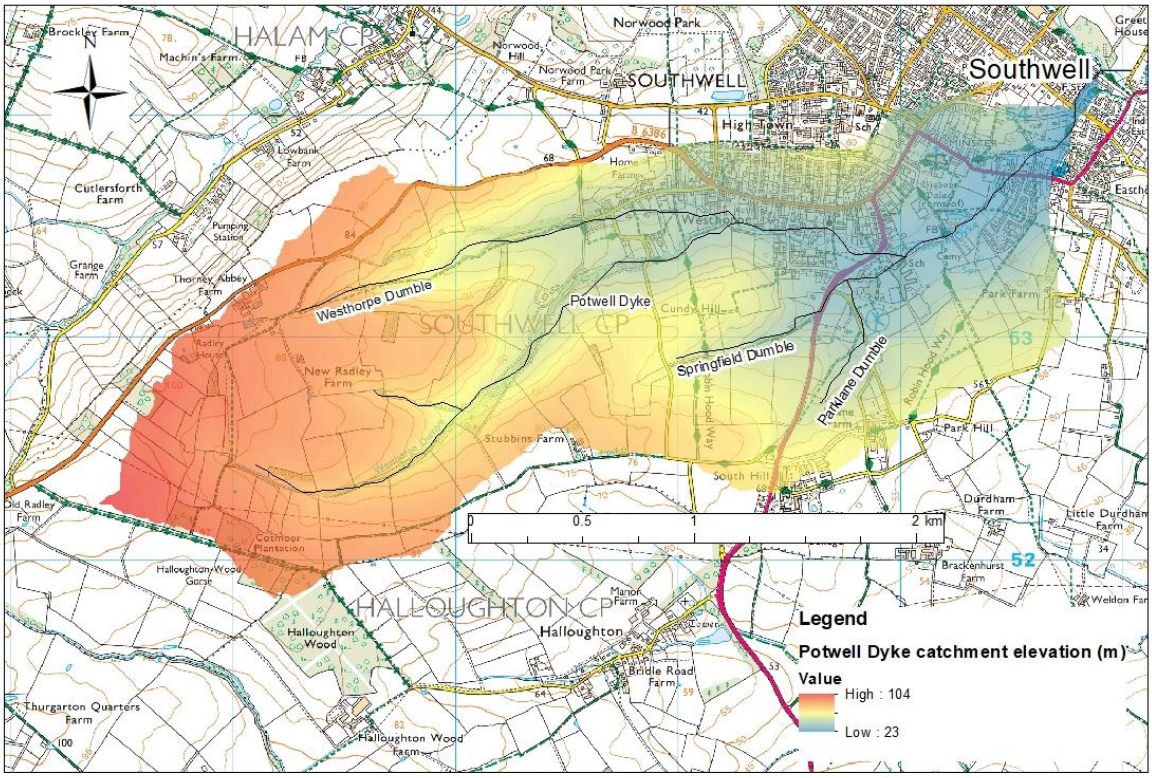

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Figure 4.6 Elevation of the Potwell Dyke catchment. (Data from EDINA Digimap).

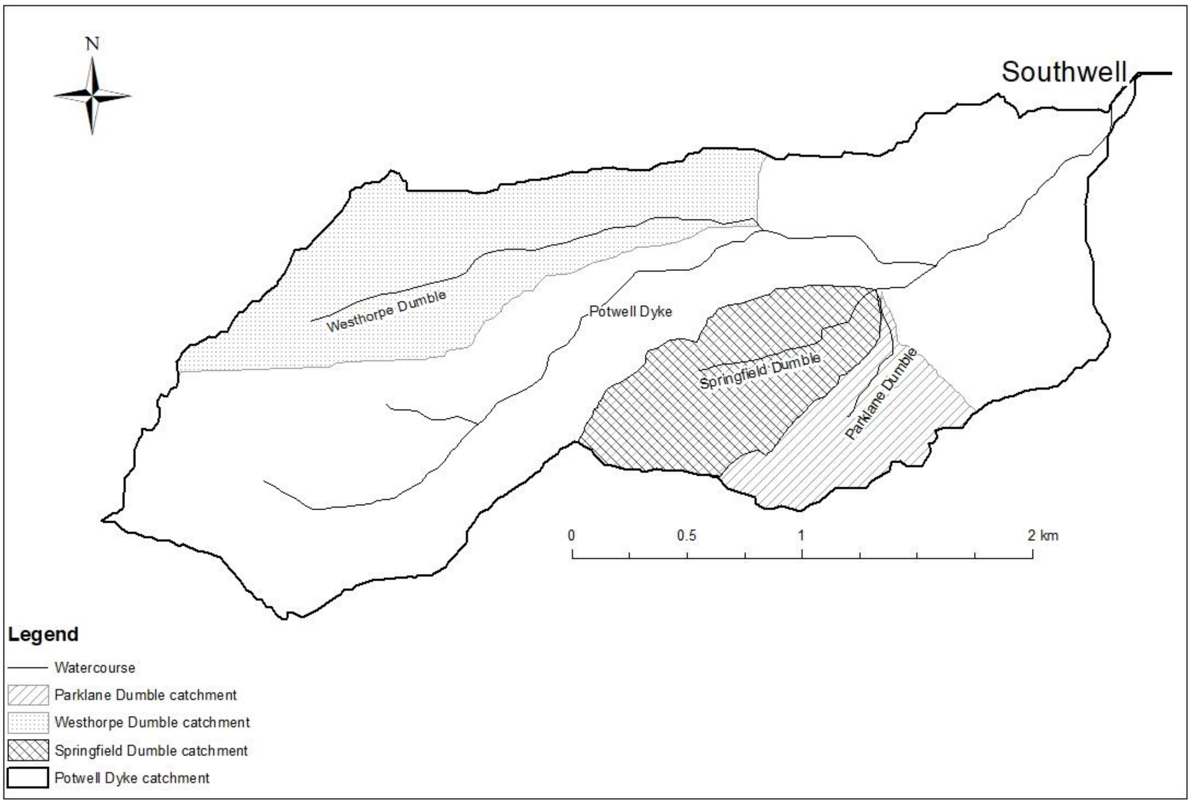

Figure 4.7 Sub-catchments of the Potwell Dyke, Southwell. (Data from EDINA Digimap).

4.3.2 Geology

Within the catchment, solid geology is Triassic and includes the Radcliffe Member which follows the Dumbles and town itself, and the Gunthrope Member which lies in the upper parts of the catchment (Figure 4.8). The Radcliffe Member is described as Mudstone, Siltstone and very fine-grained Sandstone, whilst the Gunthorpe Member is described as Mudstone (BGS, 2017).

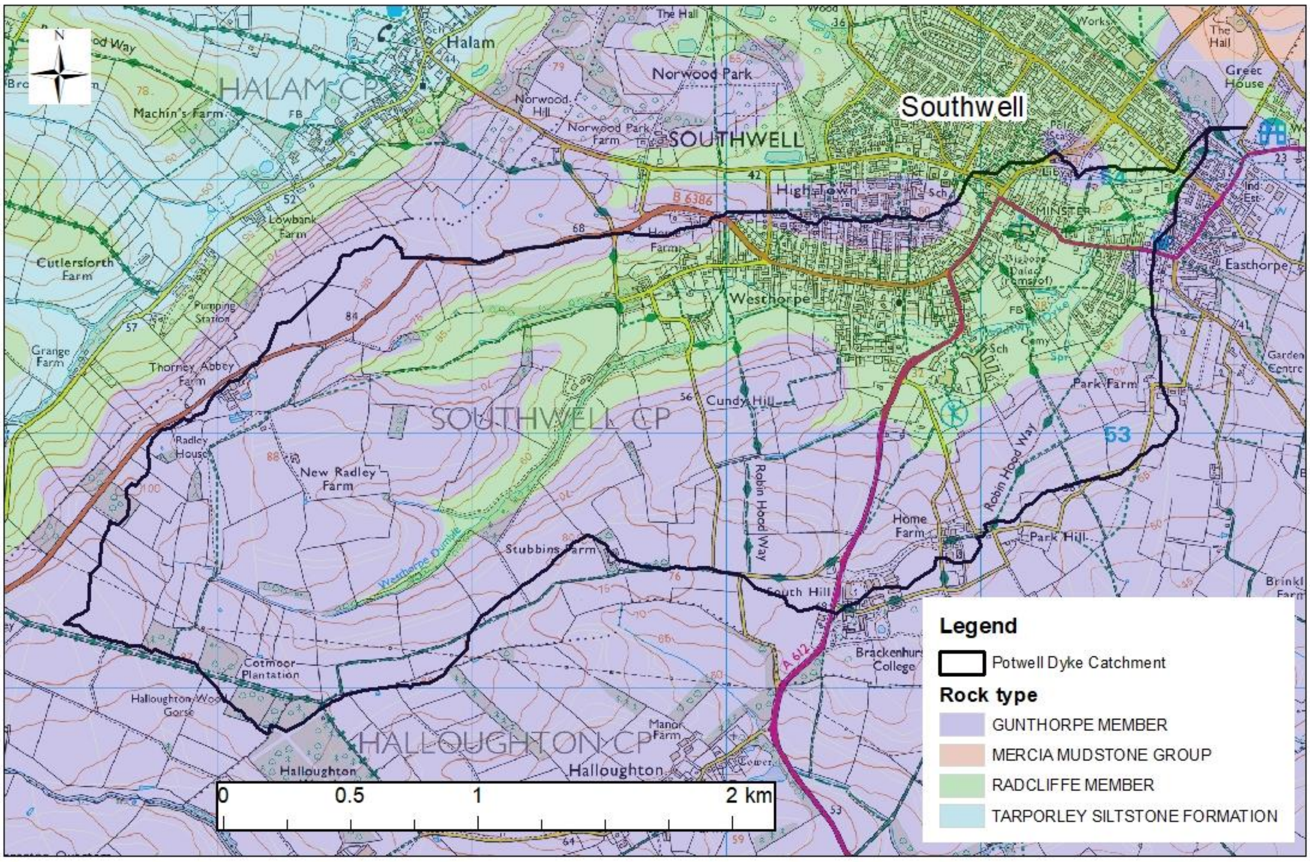

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Figure 4.8 Geology of the Potwell Dyke catchment.

4.3.3 Soil types within the catchment

Soils within the catchment are mainly clay loams which are slowly permeable (Figure 4.9; Table 4.1). Therefore, when combined with the steep catchment topography, overland flow generation is enhanced. Moreover, when left bare during warmer periods, the soils within the catchment are prone to surface crusting, which further exacerbates runoff generation in some areas (Figure 4.10). Figure 4.11 shows results of a ring infiltrometer test conducted by an undergraduate (Kopryrko, 2017). As shown in Figure 4.11, the clay soils have a very low final infiltration rate within the arable fields. As Southwell is at-risk from high magnitude, low frequency summer rainfall events, crusted clay soils with low infiltration rates within the catchment can contribute to the flooding within the town. Therefore, the catchment setting before an event is an important consideration during analysis.

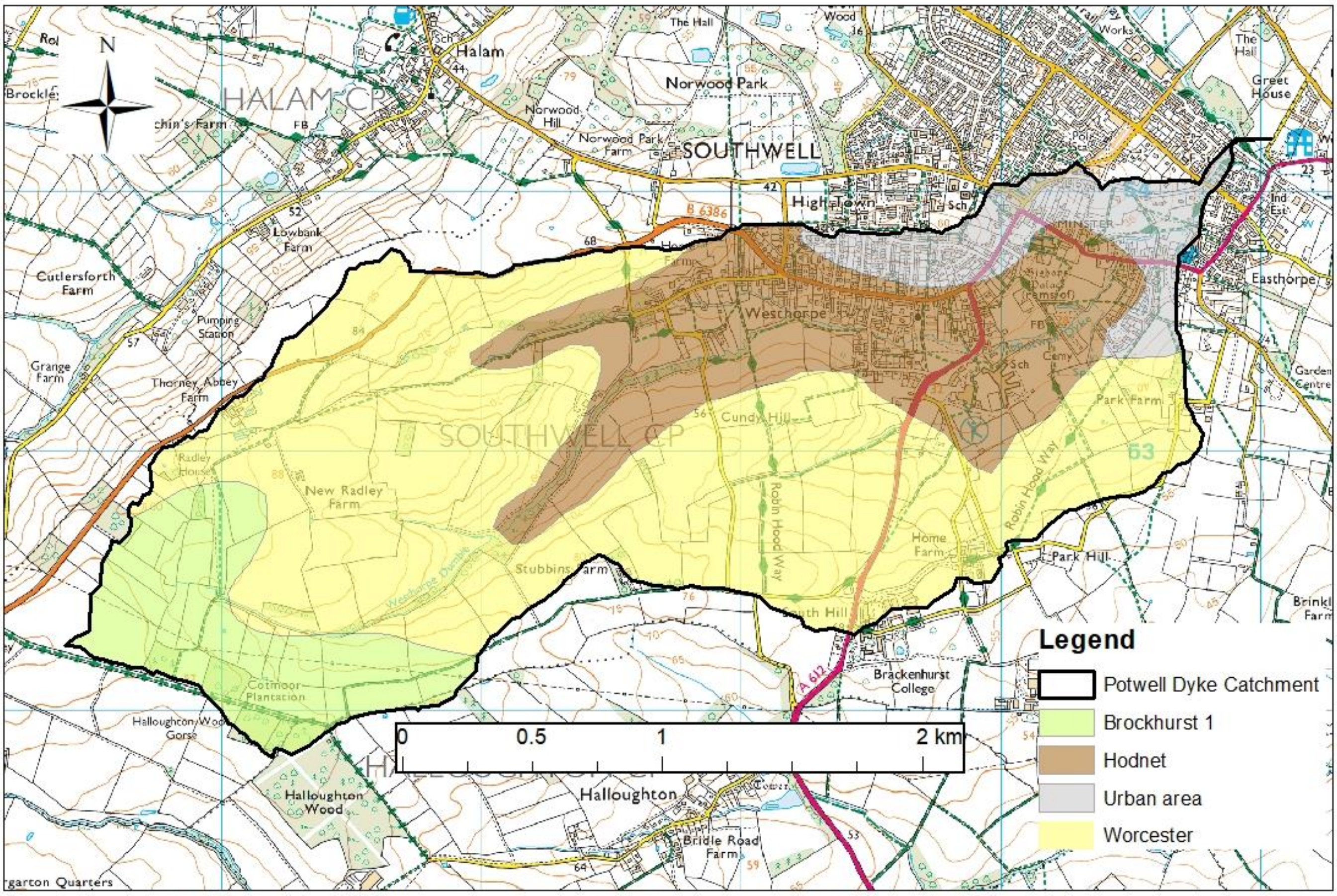

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Figure 4.9 Soil types within the Potwell Dyke catchment. Data from the Soil Survey of England and Wales, (1983).

Table 4.1 Descriptions of soils present within the Potwell Dyke Catchment (Ragg et al. 1984).

Soil Type	**Description**	**% of Catchment**
Brockhurst 1	Fine loamy over clayey with slowly permeable soils	12.3
Hodnet	Fine loamy silt or clay. Slowly permeable horizons in the subsoil	24.1
Urban	Urban or industrial land	7.6
Worcester	Stoneless or slightly stony clay loam	56

Figure 4.10 Surface crusting of clay soils within the Potwell Dyke catchment. Source: Amy Kopyrko (SPUR student, 2017).

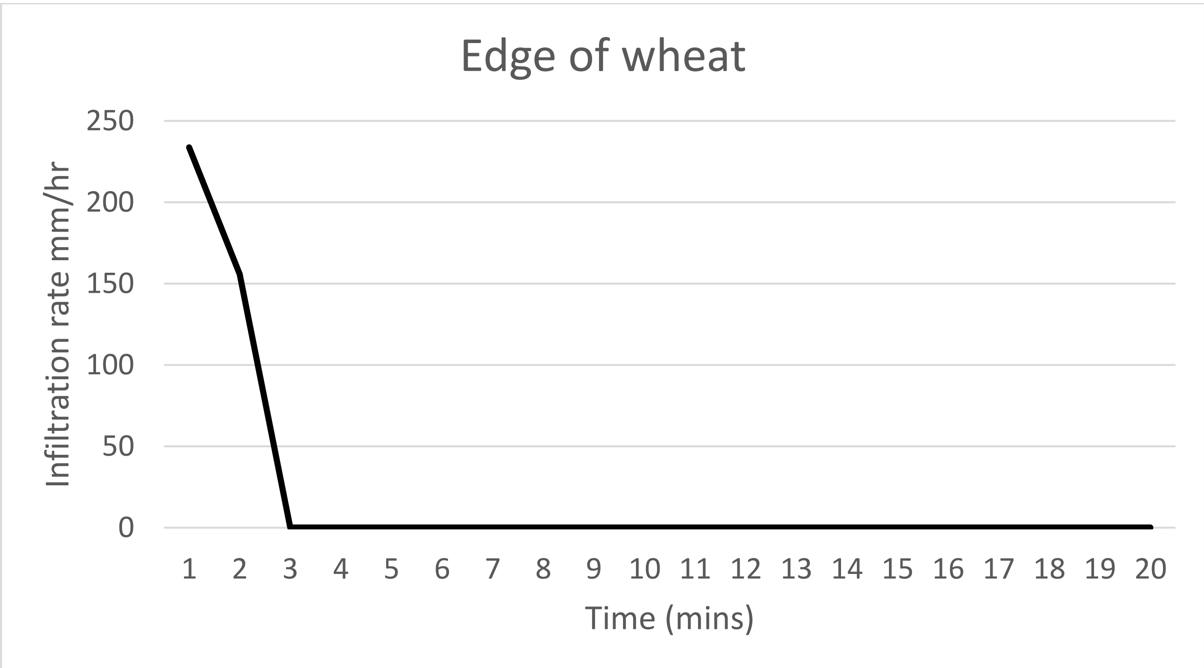

Figure 4.11 Infiltration curve measured at the edge of a wheat field in the Potwell Dyke catchment. Source: Amy Kopyrko (NTU SPUR student, 2017).

4.3.4 Land use

Land use within the catchment is mainly arable (Figure 4.12; Table 5.2) with areas of built up land in the town of Southwell itself. Within the upper reaches of the catchment, agriculture plays a significant role in the land use. This is a mix of arable and grassland farming with livestock. As agricultural land use has been linked to soil compaction (O' Connell *et* al. 2007), reduced infiltration (Pattison and Lane, 2011) and enhanced overland flow generation (Dadson *et al*. 2017) in previous studies, including that of Kopyrko and Leekham (2017), overland flow is likely to be significant during heavy rainfall within the study site.

Some small areas of woodland are located within the catchment totalling 0.4km^2. There are six major land managers within the catchment, this includes the NTU Brackenhurst campus. However, there are land managers who manage smaller areas, including individual plots of land in the upper catchment.

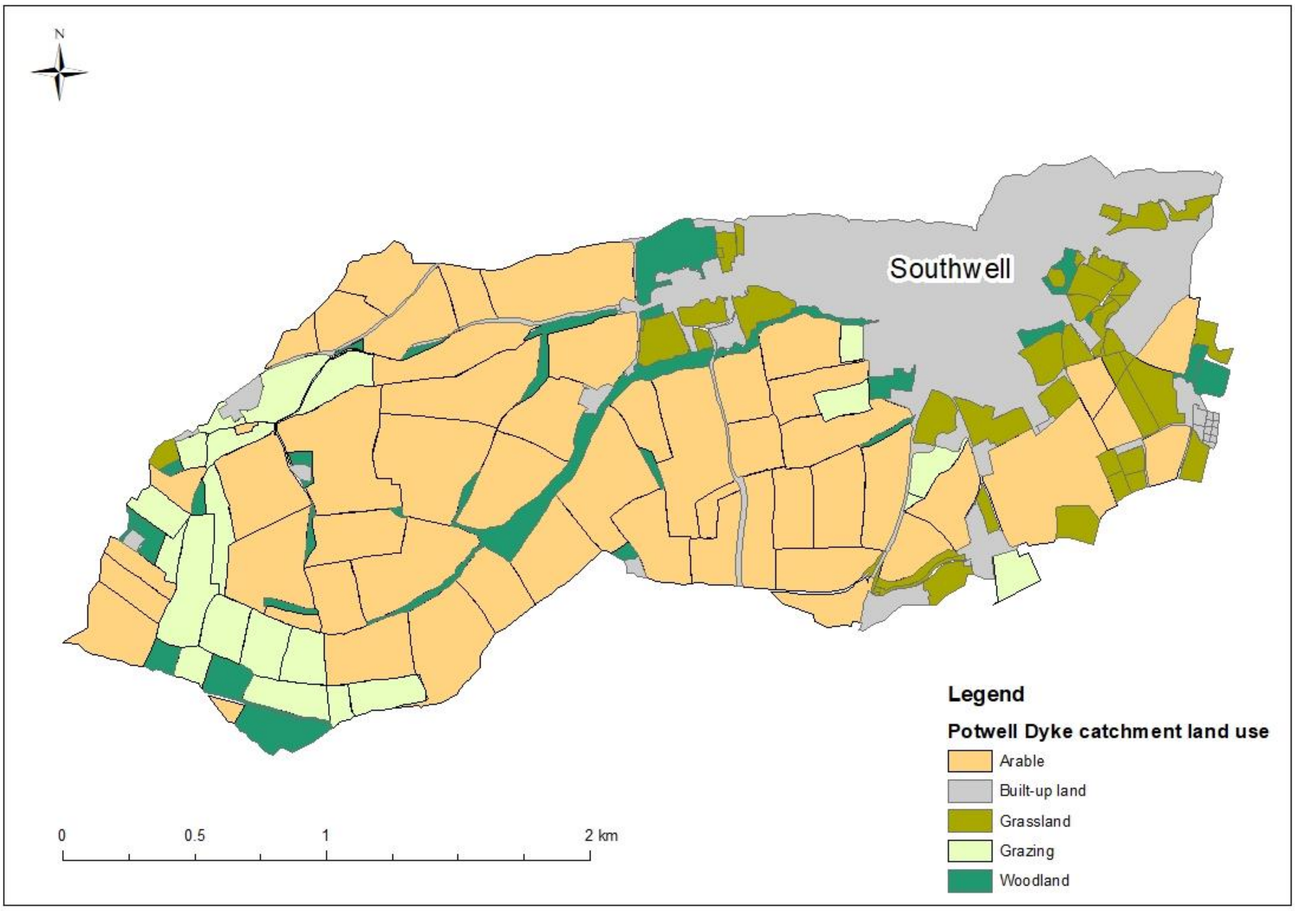

Figure 4.12 Land use within the Potwell Dyke catchment. Data collected by NTU SPUR students Hugh Leekham and Amy Kopyrko (2017).

Table 4.2 Land use percentages within the catchment

Land use	% of catchment
Arable	55.4
Built-up land	20.5
Grassland	7.8
Grazing	9.3
Woodland	6.9

4.4 Stakeholders involved within FRM in Southwell

As the river Greet is a main watercourse, the Environment Agency (EA) is responsible for flooding from the Greet under the Flood and Water Management Act (2010). Also under the Act, the lead local flood Authority (LLFA) is Nottinghamshire County Council (NCC), which is responsible for FRM within the Potwell Dyke catchment as it is an ordinary water course. Therefore, both of these bodies are considered stakeholders within FRM for Southwell.

Southwell has three levels of council: the County Council as previously mentioned, Newark and Sherwood District Council (NSDC) and Southwell Town Council (STC). As NSDC are responsible for housing and planning permissions, they too are recognised as a stakeholder as floodplain development can be influenced though them. STC provide consultation for planning and promote flood resilience within the town and so are also recognised as a stakeholder.

An important FRM stakeholder within Southwell is the Southwell Flood Forum (SFF). The SFF aims to promote flood resilience within the town but also to give local residents a say on the FRM interventions to be installed. The SFF has so far been influential within the design stages of the future FRM scheme though community events which engaged with, and transferred local knowledge to, the consultants involved within the FRM planning for Southwell (URS, 2014). The SFF has a Technical sub-group, made up of professional individuals, which has fed information to the consultants involved within the FRM planning and to NCC. Therefore, the SFF is a key stakeholder within FRM in Southwell.

The Trent Rivers Trust is an NGO which has been working with land managers within the catchment to promote the uptake of NFM. Thus, they too are considered a stakeholder within FRM for Southwell. The local land managers themselves are additionally acknowledged as a stakeholder within the catchment as they are influential in the uptake of NFM.

Finally, the local community are considered stakeholders within this research. The local community can be influential in NFM uptake through support for its implementation or can create argument against its use. Therefore, the community must be made aware of the research, its aims, and the interventions that are to be installed.

It has been demonstrated within the literature that the implementation of natural flood management has a multitude of complex and diverse barriers which do not adhere to any individual research disciplines a suitable interdisciplinary methodological approach needs to reflect this. Interdisciplinary studies are described as when researchers go beyond their discipline to create a new theory and methodology in order to solve wider problems (Youngblood, 2007). However, Interdisciplinarity only occurs when research methods are drawn from disciplines and their insights are subsequently integrated (Newell, 2001). It is therefore imperative that an interdisciplinary methodology brings together the findings of the research.

The next five chapters aim to assess the barriers to NFM uptake using an interdisciplinary approach but also bring these findings together. The first four data Chapters (5-8) explain the methods, show the results and discuss the findings of the research relating to each key question set out in Chapter 1. Chapter 9 brings the findings together in an overall discussion in order to take a truly interdisciplinary approach in answering the question: what are the barriers to NFM uptake and how do they apply in practice.

5. Hydrological impacts of natural flood management

5.1 Introduction

This chapter presents results from the field experiment showing the observed impacts of NFM intervention on the hydrograph as well as any observed changes in hydrological processes. As has been found within the literature review, a lack of scientific evidence of NFM benefits presents a barrier to uptake. This chapter offers findings which can contribute towards the current evidence base. A focus is made on the storage of overland flow in bunds and its impact on peak flows. The results are discussed along with implications for effectiveness when NFM is upscaled to larger catchments and when used to mitigate against larger magnitude rainfall events.

5.2 Methods

5.2.1 Hydrological data collection

5.2.1.1 Rainfall data

Rainfall data were collected at Nottingham Trent University's Brackenhurst Campus (SK 695 520), approximately 1km South of Southwell. Two types of rain gauges were used. A Casella tipping bucket rain gauge collected data for the whole duration of the project. Alongside this, an Ott tipping bucket rain gauge on an automatic rain station also collected data until May 2016. However, due to damage by livestock, that rain gauge was replaced with an Ott Pluvio weighing rain gauge in August 2016. Data were recorded at minute intervals with a resolution of 0.2mm. This was converted to 5 minute data, to allow for the lag time between peak rainfall intensity and peak stream discharge (Q) and stage to be calculated.

5.2.1.2 Stage data (water levels)

Stage data were collected at multiple sites on the Potwell Dyke, Springfield Dumble and Parklane Dumble water courses (Figure 5.1). Details are shown in Table 5.1.

The longest temporal record is located on Potwell Dyke at the Park Lodge site (site 1), which was installed by the academic supervisor prior to this project and has been collecting stage data since December 2013. Between December 2013 and June 2016 the logger was recording stage at ten minute intervals. In June 2016 this was altered to five minute interval recordings.

Upstream and downstream stage loggers were installed within the Springfield and Parklane Dumbles in October 2015 (sites 2, 4, 5 and 6). These loggers were programmed to record stage at 5 minute intervals. In December 2016, three additional telemetric stage loggers were installed by Hydrologic Services at sites 1, 2 and 7, with a fourth at another location within the town, but outside the scope of this research. Again, the telemetric loggers installed were set to record water levels (stage) at five minute intervals.

The monitoring network created was designed to allow for comparison between upstream and downstream peaks within the catchment and subcatchments. At least a year of pre-intervention data (13 events) was collected within each of the watercourses, so that a pre and post intervention comparison of hydrograph characteristics could be undertaken.

In May 2017, following NFM interventions made within the catchment, three additional stage loggers were installed within constructed bunds and one within a stream restoration reach (site 3). The bunds chosen for monitoring are Second Sunnydale, Common Mere and Parklane Close. The loggers installed within the bunds and restoration were programmed to record stage at five minute intervals. Section 5.2.2.2 gives details of bund locations and construction.

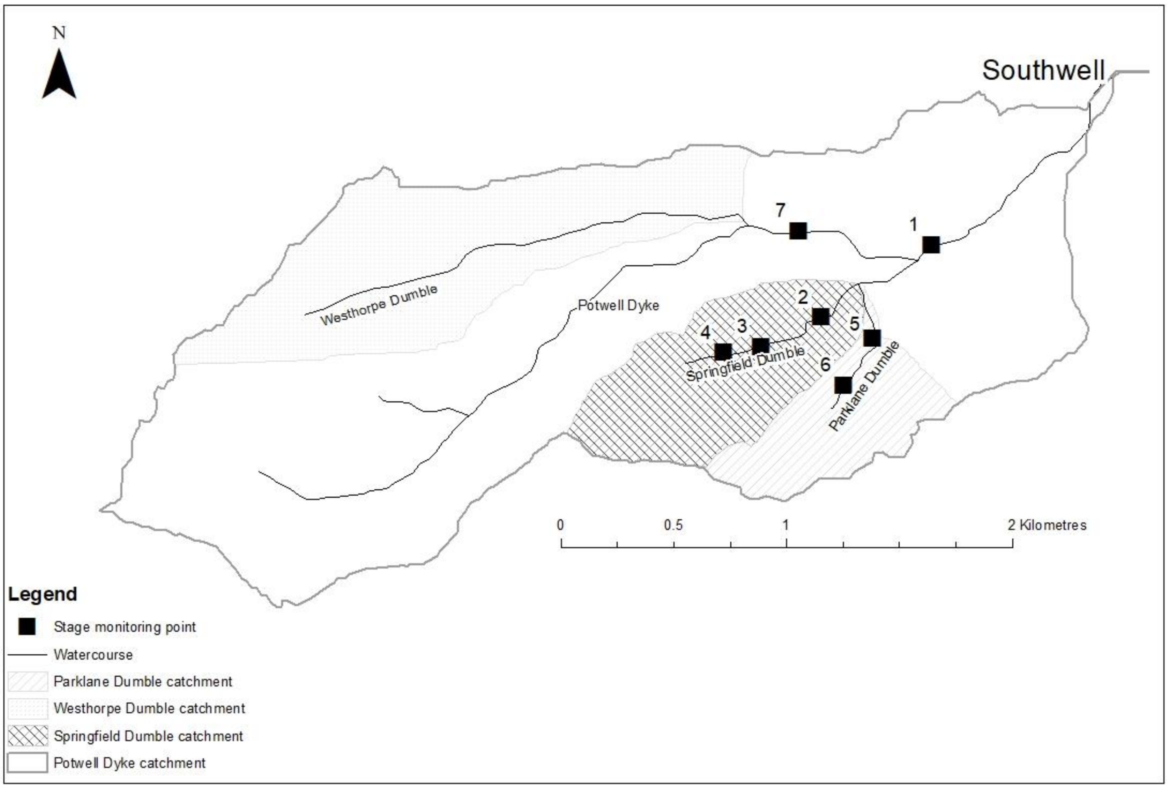

Figure 5.1 Stage monitoring points in watercourses within the Potwell Dyke catchment.

Table 5.1 Stage loggers installed within Southwell watercourses.

Site	Logger type	Installation date	Name	Acronym	Grid Ref
1	Ott Pressure transducer and telemetric pressure transducer	December 2013 and December 2016	Potwell Dyke	PD	SK699534
2	Diver and telemetric pressure transducer	November 2015 and December 2016	Lower Springfield Dumble	LSD	SK695530
3	RS Hydro Solinst pressure transducer	May 2017	Springfield Restoration	SR	SK693530
4	Ott Pressure transducer replaced by Ott Thalimedes float and counterweight in August 2016	November 2015	Upper Springfield Dumble	USD	SK691529
5	Ott Thalimedes float and counterweight	November 2015	Lower Parklane Dumble	LPD	SK69818
6	Ott Thalimedes float and counterweight	November 2015	Upper Parklane Dumble	UPD	SK697528
7	Telemetric pressure transducer	December 2016	Holloughton Road	HR	SK695534
Bunds	Ott Thalimedes float and counterweight	May 2017	-	-	-

Table 5.2 Logger failures during the research

Logger Name	Date of failure	Type of failure
Lower Springfield Dumble	15/5/16- 9/6/16	Memory failure
Lower Springfield Dumble	22/2/18- 3/3/18	Memory failure
Upper Springfield Dumble	8/06/16- 11/07/16	Logger malfunction
Upper Springfield Dumble	11/07/16- 25/08/16	Logger malfunction
Upper Parklane Dumble	30/11/16- 17/2/17	Logger bypassed by water
Potwell Dyke	25/9/18- 15/11/18	Battery failure

5.2.1.3 *Rating curves*

It was not possible to construct gauging structures at each monitoring site as they were on private property and close to an urban area, so rated sections were used. Rating curves were created using the velocity area method, to calculate discharge at stage logger sites within the watercourse (Shaw *et al*. 2011). An Ott MF pro electromagnetic velocity meter was used to measure velocity within the channel at a range of flows. Typically, 8 – 10 depths were used. The mean section method was then applied to calculate discharge in Excel (Shaw *et al.* 2011). Results were plotted against the corresponding stage ruler reading, observed at the time of discharge measurement. The resulting rating equation was then used to calculate equivalent discharge at each of the recorded stages at that site. An example is shown in Figure 5.2. Discharge measurements were made during both low and high flows, giving a range of values for use within the rating curve calculation.

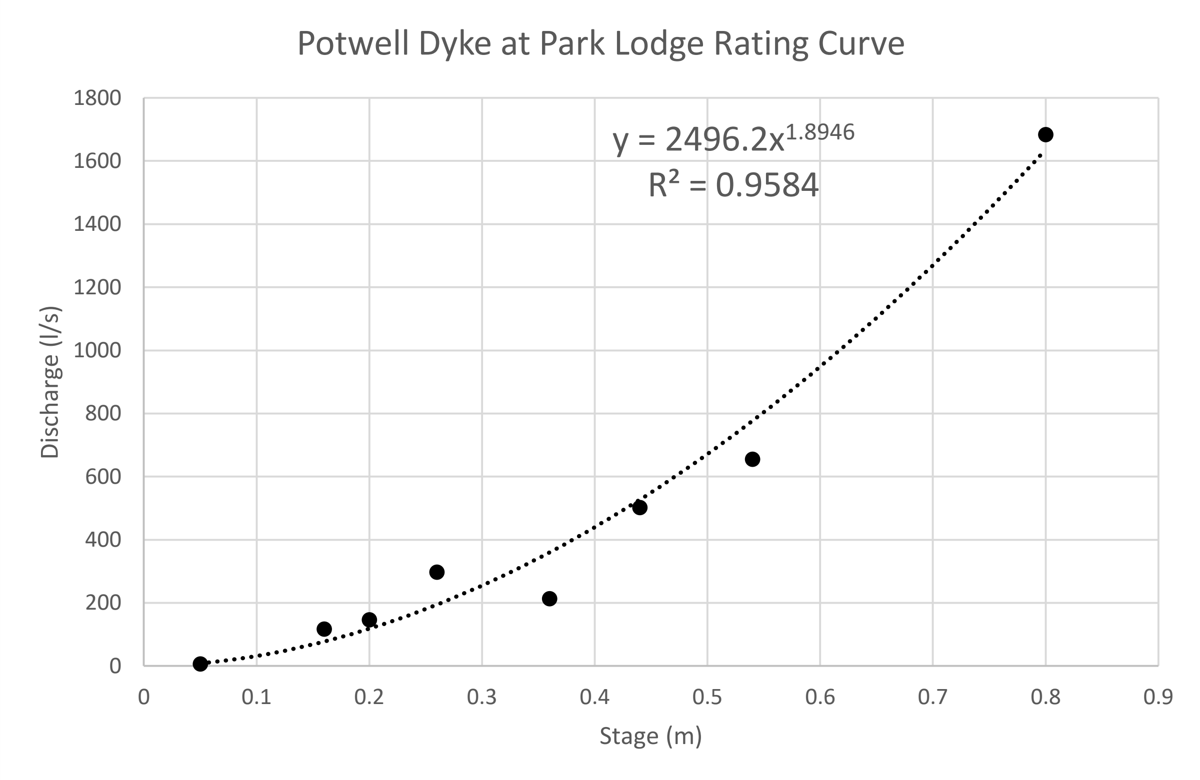

Figure 5.2 Example of a rating curve: Potwell Dyke at Park Lodge.

5.2.2 *NFM intervention design*

A key question of this research is to assess the extent to which NFM can impact on hydrograph characteristics. Therefore, an objective of this research was to design and install NFM within the catchment. Section 5.2.2.1 explains the stream restoration intervention, section 5.2.2.2 the earth bunds and section 5.2.2.3 the LWD dams.

NFM interventions were implemented in both the Springfield and Parklane Dumble subcatchments of the Potwell Dyke (Figure 5.3). A stream restoration, four earth bunds and eight LWD dams were installed in the Springfield Dumble catchment (Figure 5.4). One earth bund and five LWD dams were installed in the Parklane Dumble catchment. Ten of the LWD dams were installed in June and July 2016. The restoration and bund construction were undertaken between October and November 2016. Three more LWD dams were then installed within the Springfield Dumble restoration reach in June 2017.

For this project, the earth interventions were constructed at a discounted rate as the contractor had been previously flooded during the 2013 event and so wanted to make a positive contribution towards flood risk for the town. The bunds and restoration works had a budget of £4000 which was all spent. The leaky barriers had a budget of £1000 of which £700 was spent. However, these costs do not include staff time which was spent on research, design, landowner engagement or LWD installation.

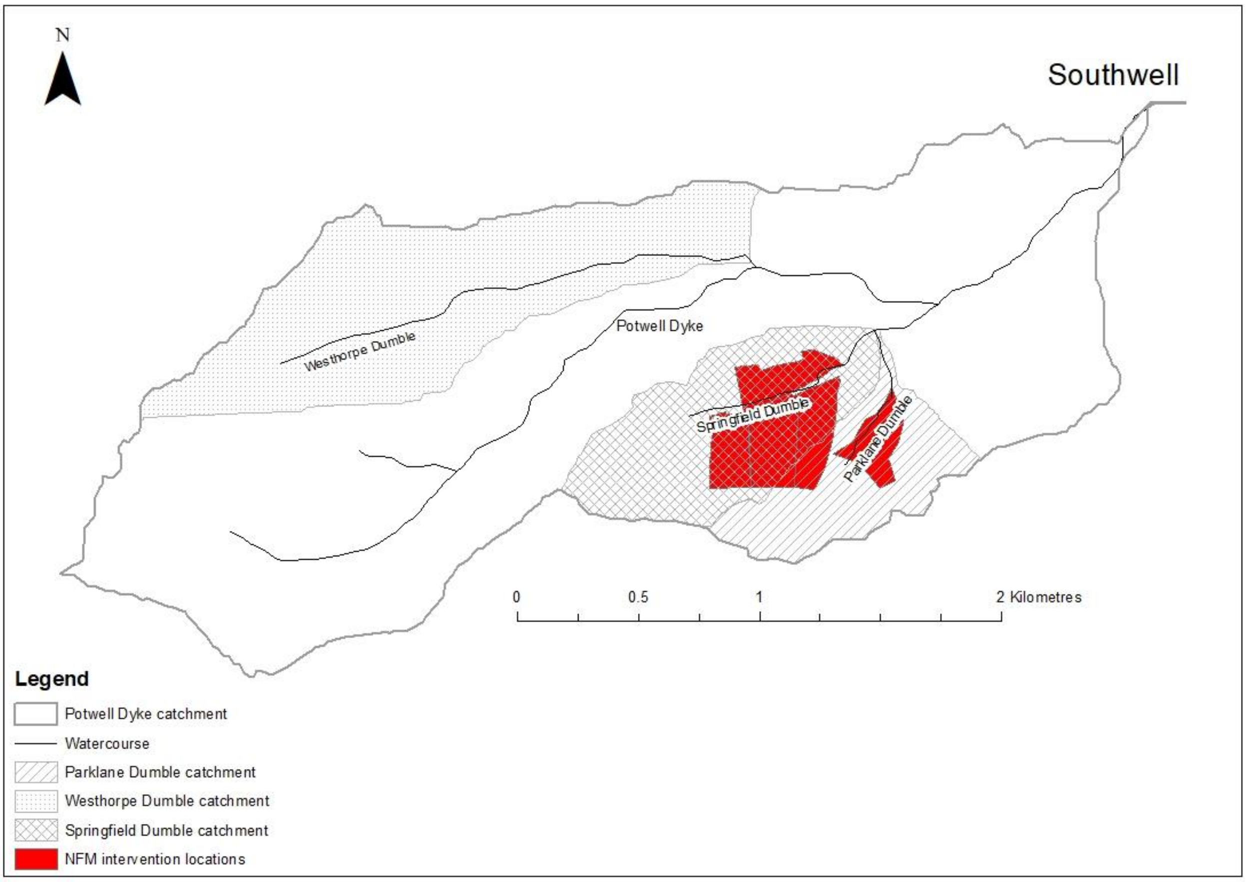

Figure 5.3 Location of NFM interventions within the catchment.

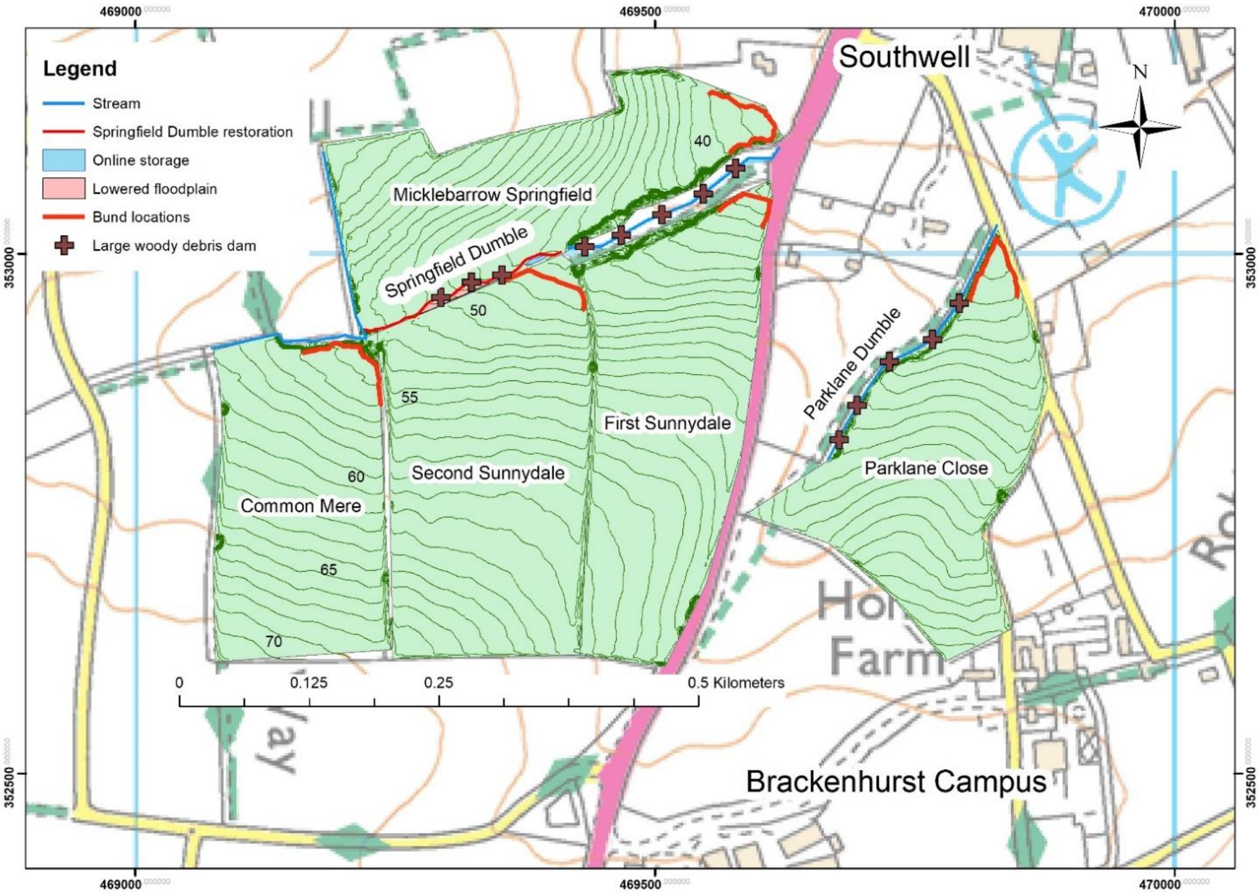

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Figure 5.4 NFM interventions installed within Nottingham Trent University's Brackenhurst campus.

5.2.2.1 Stream restoration

As part of the natural flood management interventions for this research, a stream restoration was conducted on the Springfield Dumble on land belonging to Nottingham Trent University (Brackenhurst Campus), just upstream of the town of Southwell. The stream was in a straightened channel reach and has a culvert at the lower end going under a field track, which has been left unaltered. Figure 5.5 shows the channel prior to restoration. An OS map from the 1880s was used to identify the original channel planform (Figure 5.6), which was also more sinuous, and an RAF aerial photograph from 1947 provided evidence that the channel straightening had occurred after this date. Using a contractor funded by the Environment Agency (Trent RFCC local Levy) for this project, the straightened channel above the culvert was restored to its meandering predefined state (Figure 5.7), alongside a slightly lower floodplain and some online storage. The channel planform for the restoration was set out using a Trimble RC2 GPS. Large woody debris were installed in the channel, to reconnect the channel with the lowered floodplain. This was done after the channel had re-vegetated to limit erosion. Native tree saplings were planted along the banks of the restoration and on the lowered floodplain section, intended to increase channel roughness and reduce soil erosion and consequent downstream sedimentation.

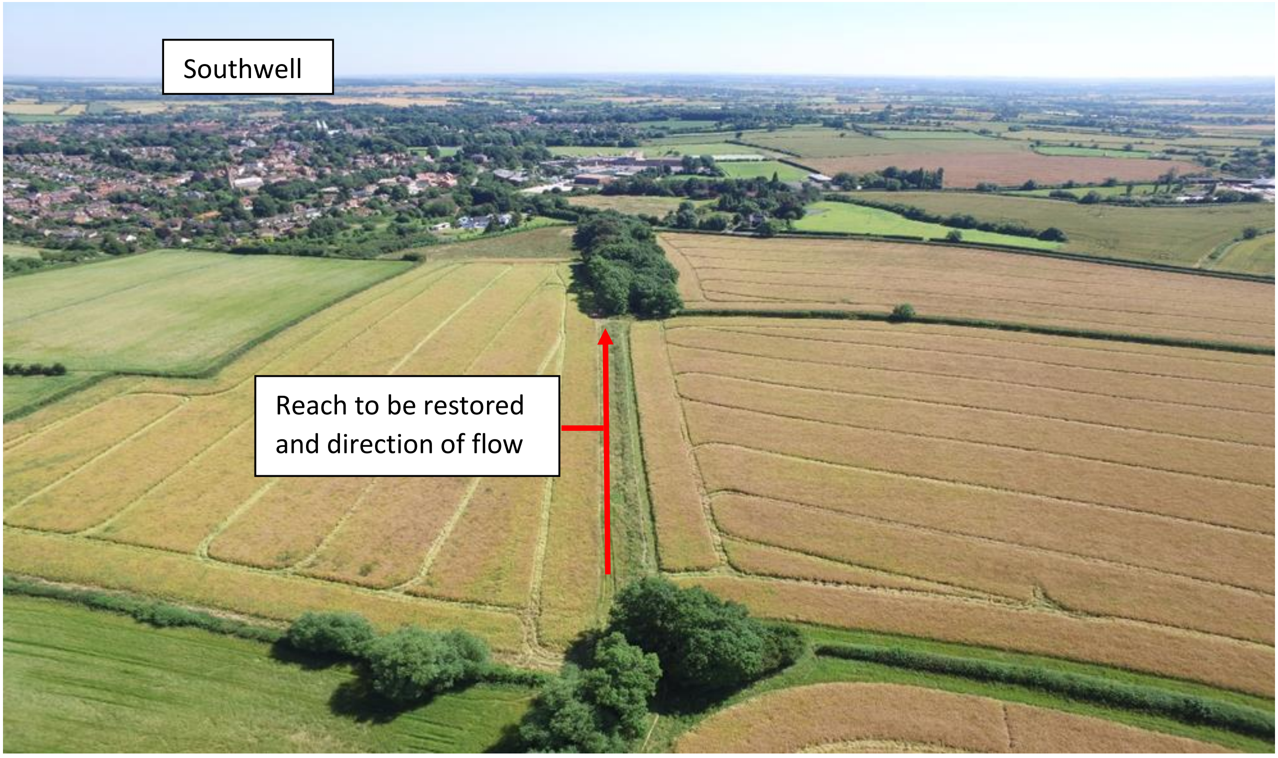

Figure 5.5 Springfield Dumble pre-restoration and Southwell viewed from the west (Image: Dr Steven Godby).

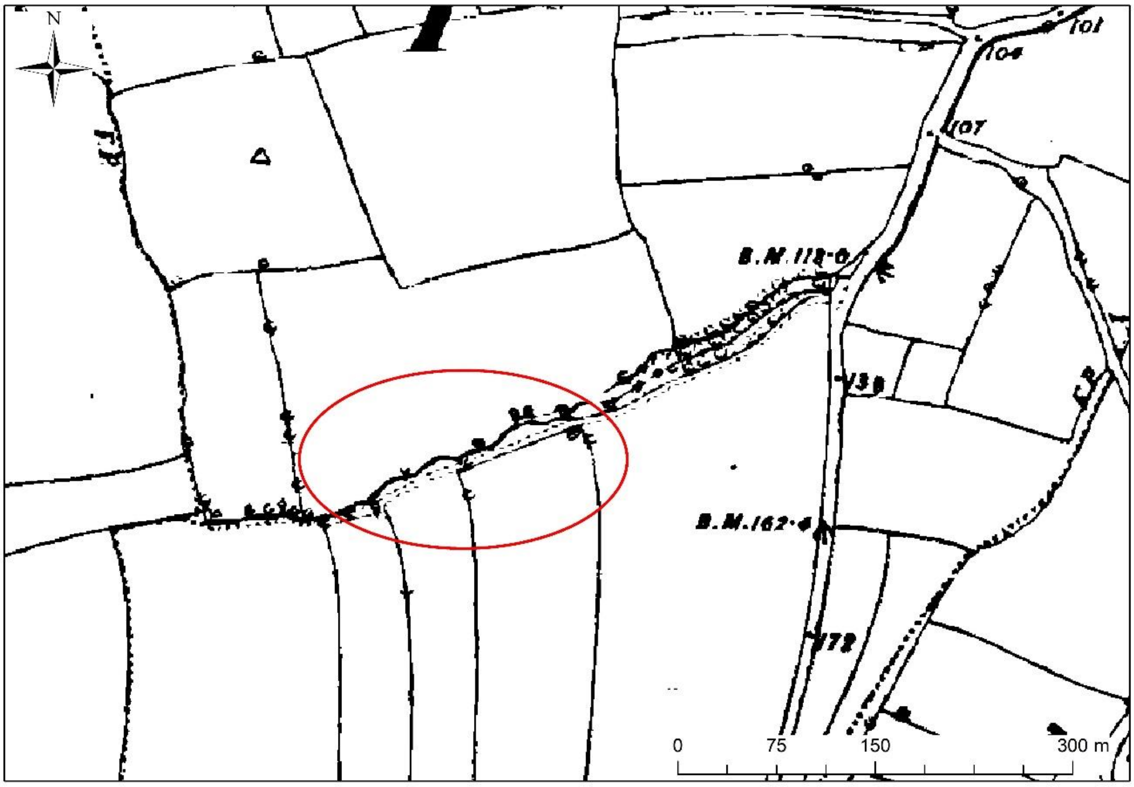

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Figure 5.6 Historic map of the Springfield Dumble (highlighted by red ellipse).

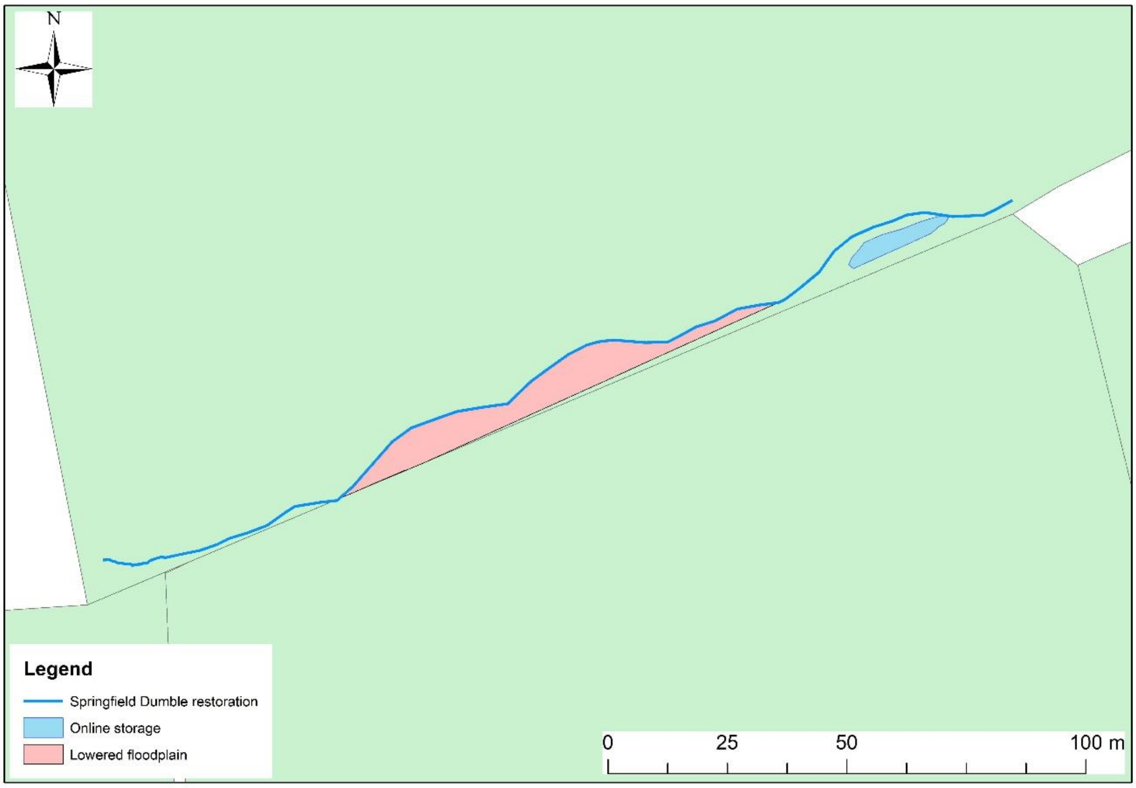


Figure 5.7 Springfield Dumble restoration plan.

Stream gradients were calculated using a Leica 1200 dGPS together with a Leica automatic level. Points from the dGPS were post-processed using RINEX data from the Ordnance Survey to improve accuracy. Points obtained using the automatic level were related to dGPS points and input into ArcMap after surveying. Distances between points were calculated within ArcMap, to create a longitudinal profile (Figure 5.8).

Figure 5.8 shows the longitudinal profile of Springfield Dumble. The upstream elevation of the restoration reach is 50.65m AOD whilst the downstream elevation upstream of the culvert is 45.64m AOD, giving a fall of 5.01m. The distance between the two points is 175m meaning that a gradient of 0.029 was calculated. The gradient for the section downstream of the proposed restoration was difficult to calculate, given a steep drop (knick point) in elevation immediately below the culvert at the downstream end of the restored reach. Excluding the data from the steep drop and starting from 203m along the transect gives a gradient calculation of 0.03 for the downstream section. The overall gradient for the stream as a whole (including the steep drop) was 0.04.

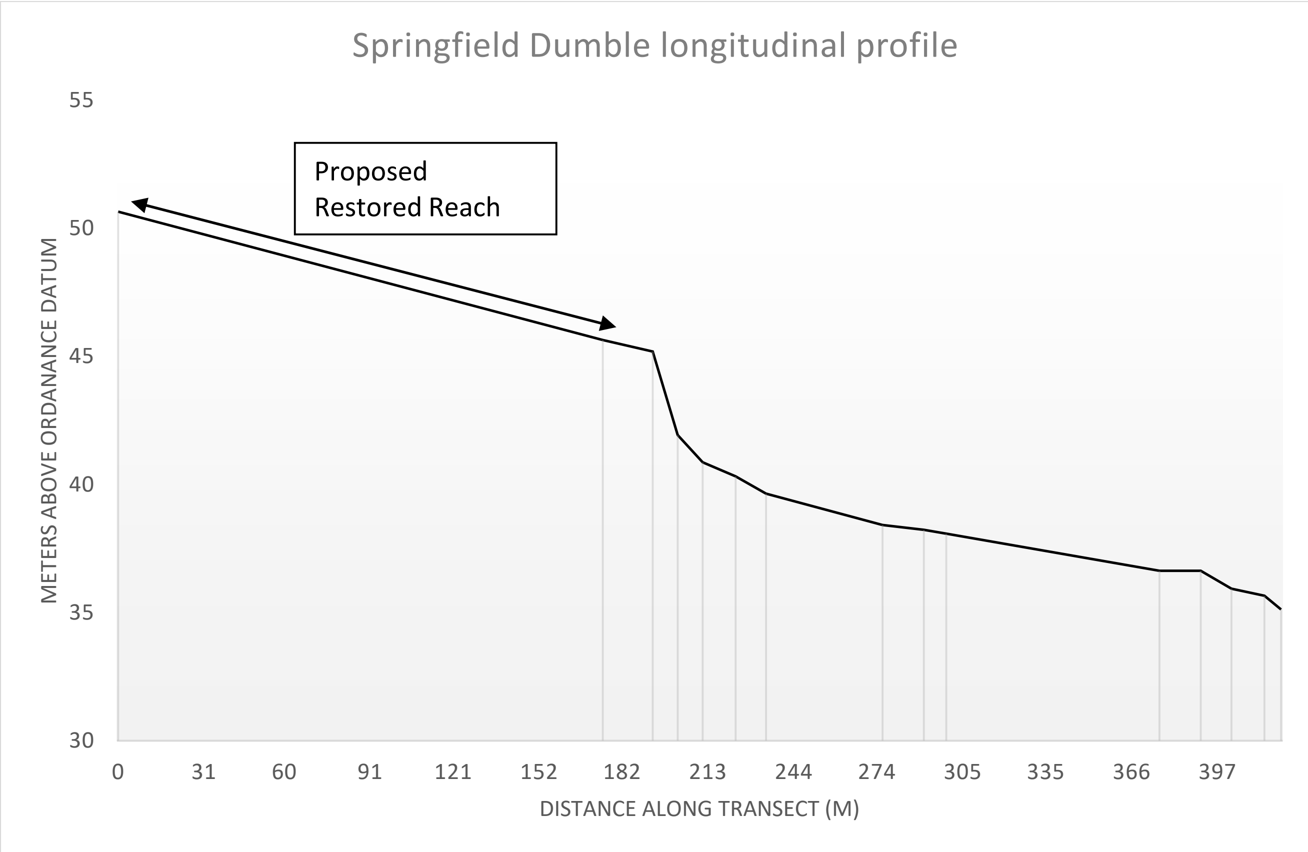


Figure 5.8 Longitudinal profile of the Springfield Dumble.

The restored reach was designed as a two stage channel (Figure 5.9). To calculate storage, the dimensions from a typical cross section were used. The volumes were calculated in two parts, to reflect the two stages of the channel. Pre restoration, the storage capacity of the channel was less than $100m^3$.

The proposed lowered floodplain cross section was based on events recorded at a water level logger located upstream of the restored reach (Upper Springfield Dumble, data available Sept 2015-Sept 2016). During this time period, five events were recorded that equalled or exceeded 0.2m depth. Therefore, the lowered floodplain was designed to be 0.2m above the restored streambed.

The deepest part of the restored channel has a length of 213.8m and so an indicative storage capacity of 60m^3 (213.8 long x 0.8 wide x 0.35 deep). The second stage of the channel storage capacity was calculated using the area of a trapezoid formula ((a+b)/2)xh) which gives a cross section of 2.61m^2. Multiplied by the length of the restored channel gave a second stage channel volume of 558 m^3. From ArcMap, the additional volumes of the lowered floodplain and online storage are 200m^3 (approx.) and 71m^3 respectively. Thus, a combined storage of 889m^3 was calculated.

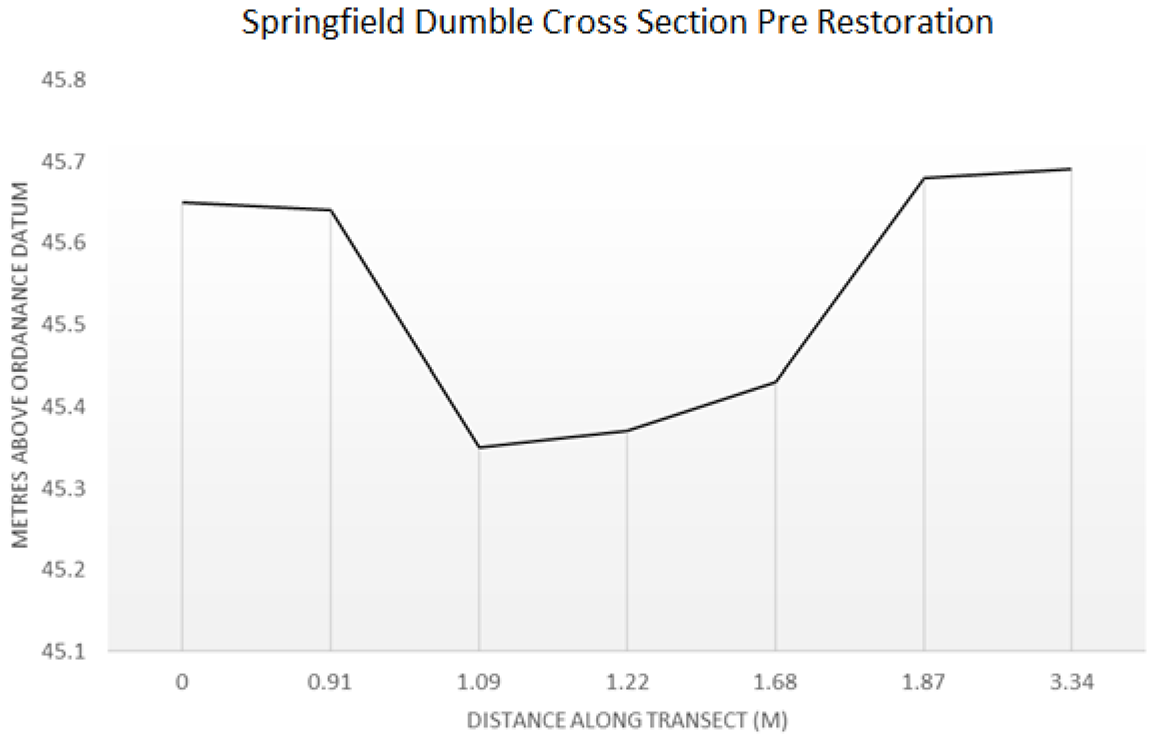


Figure 5.9a Springfield Dumble cross section pre restoration.

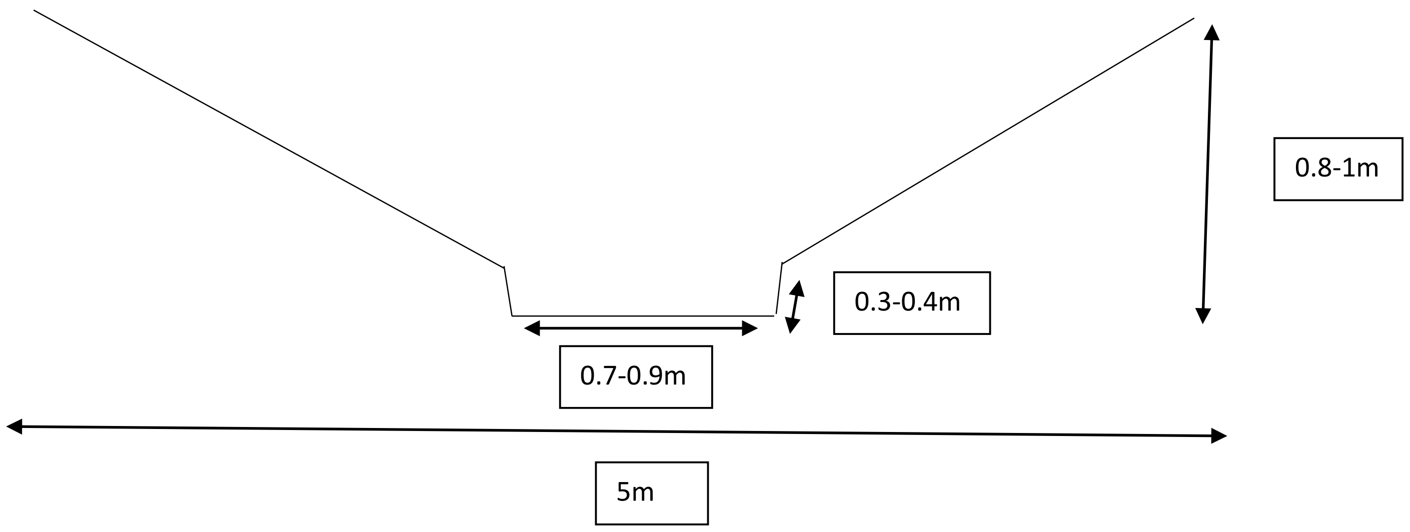
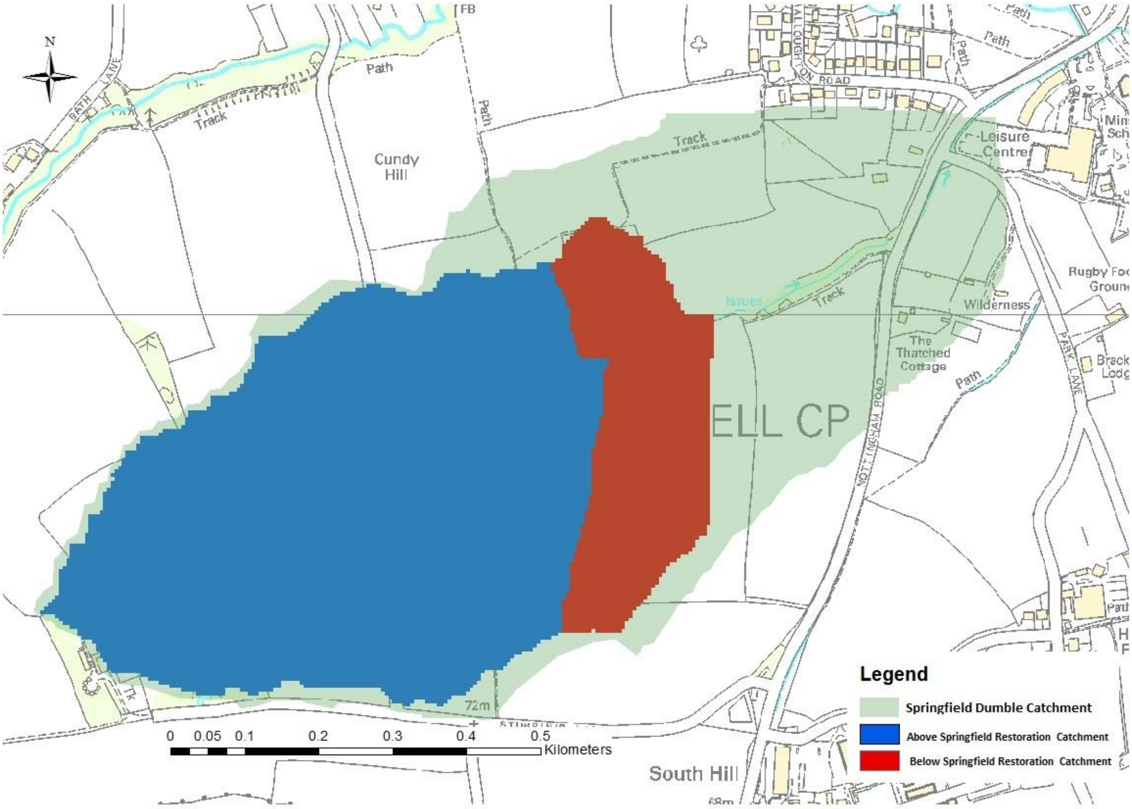


Figure 5.9b Springfield Dumble proposed restored reach channel design (approx. measurements). All measurements are approximates. Channel design has been replicated from Lower Springfield Dumble natural cross sections.

Ordnance Survey 5m resolution DTM ground elevation data for Southwell, Nottinghamshire were downloaded from EDINA. A flow accumulation calculation using the DTM data in ArcGIS gave a pour point for the Springfield Dumble close to Southwell Leisure Centre (NGR SK 698 533). This was used to calculate the catchment area. Pour points were then added (and used to calculate catchment sizes) both directly above the planned restoration (SK 69241 52937) and at the lower end of the restoration reach (SK 69384 52998) as shown in Figure 5.10.

The Springfield Dumble catchment has a calculated area of 0.65km^2. Above the restored reach has a catchment size of 0.31km^2, with the lower end of the proposed restoration having a calculated catchment size of 0.39km^2 (Figure 5.10). Thus, 1mm of rain falling on the catchment upstream of the restoration (saturated) would give a volume of 313m^3 (0.001x313000). 1mm of rain falling on the catchment to the lower end of the restoration (saturated) would equal 393m^3 (0.001x393000). A post restoration image is shown in Figure 5.11.



Scale 1:10000, Tiles: sk65se,sk75sw, Updated: 22 March 2013, Ordnance Survey (GB),
Using: EDINA Digimap Ordnance Survey Service, <http://digimap.edina.ac.uk>, Downloaded: 2015-10-08

Figure 5.10 Catchment delineation of Springfield Dumble.

Figure 5.11 Springfield Dumble post-restoration (April 2017) and Southwell, viewed from the west (Image: Dr Steven Godby).

5.2.2.2 Earth bunds

Five earth bunds were installed in fields on the Brackenhurst Farm owned by Nottingham Trent University. One bund was constructed in the Parklane Dumble subcatchment, and four in the Springfield Dumble subcatchment. Locations of the bunds were determined by two methods. First, flow accumulation was conducted within ArcGIS to ascertain where overland flow would accumulate within each available field (Figure 5.12). The likely storage volume behind each bund (Table 5.3) was calculated in ArcGIS using a 2m grid DSM purchased from GetMapping plc, because there was a gap in the LiDAR data available from the Environment Agency. A site walkover during rainfall confirmed overland flow paths, and any areas of ponding which indicate ideal areas for potential water storage.

The bunds were constructed of the earth excavated from the channel restoration, with an initial key trench and compaction of the earth to improve stability. The height of each bund was designed to be around 1m above the existing ground elevation. Each bund has an outlet pipe at its base with an inner diameter of 20cm. A reducer has been used to restrict the pipe diameter to 10.5cm. Drainage times for each bund are shown in Table 5.4, using the two diameters. Drainage times were estimated using an adaptation of Benoulli's equation.

$$t = \frac{r_c^2 2\sqrt{h}}{r_p^2 \sqrt{2g}}$$

Where t represents time (seconds), r_p the radius of the pipe (m), r_c the area of the cylinder (m) and h the pressure head (m).

Equation 5.1

Once constructed, the bunds were surveyed using a Trimble geo7x GPS. Data were post-processed and storage volumes were calculated using ArcGIS. The natural neighbour method was used to interpolate points into raster data. Using the DEM created, the maximum flood extent was determined by calculating a contour at the maximum bund height and then digitising the area. The flood extent was then used to clip the raster data in order to calculate the maximum storage volume.

Modifications to the original plans were necessary on site during construction, including the excavation of earth from within the bund storage area in the Micklebarrow Springfield and Parklane Bunds. Surveyed (actual) capacities are therefore different from those estimated in advance. Results are shown in Table 5.3.

Table 5.3 Proposed bund storage capacities

Bund (by field name)	Bund length (m)	Pre-construction estimated bund storage capacity (m^3)	Surveyed bund storage capacity (m^3)
First Sunnydale	86	149	62
Second Sunnydale	103	457	340
Common Mere	128	711	630
Micklebarrow Springfield	142	613	866
Parklane Close	132	568	322
Total:		**2498**	**2220**

Table 5.4 Proposed bunds time to empty

Bund (by field name)	Time to empty (hours) (d=20cm)	Time to empty (hours) (d=10.5cm)
First Sunnydale	0.7	2.4
Second Sunnydale	0.9	3.1
Common Mere	1.3	4.5
Micklebarrow Springfield	1.4	5
Parklane Close	1.2	4.9

The catchment area for each bund was calculated in ArcGIS. Some assumptions were made. First, as each field has raised hedgerow borders, water cannot easily pass over these barriers and so the catchment edge for some bunds is the perimeter of the field. A flow accumulation model created within ArcGIS shows that overland flow moves towards the corner of the fields and the bund positions (Figure 5.12). Figure 5.13 shows the catchment area for each bund and Figure 5.14 the indicative extent of temporary ponding if water is at a maximum of 1m depth. Figure 5.15 shows Common Mere bund after vegetation has established. Water has been stored following a rainfall event. Table 5.5 shows catchment sizes for each bund and runoff calculations based on a saturated catchment.

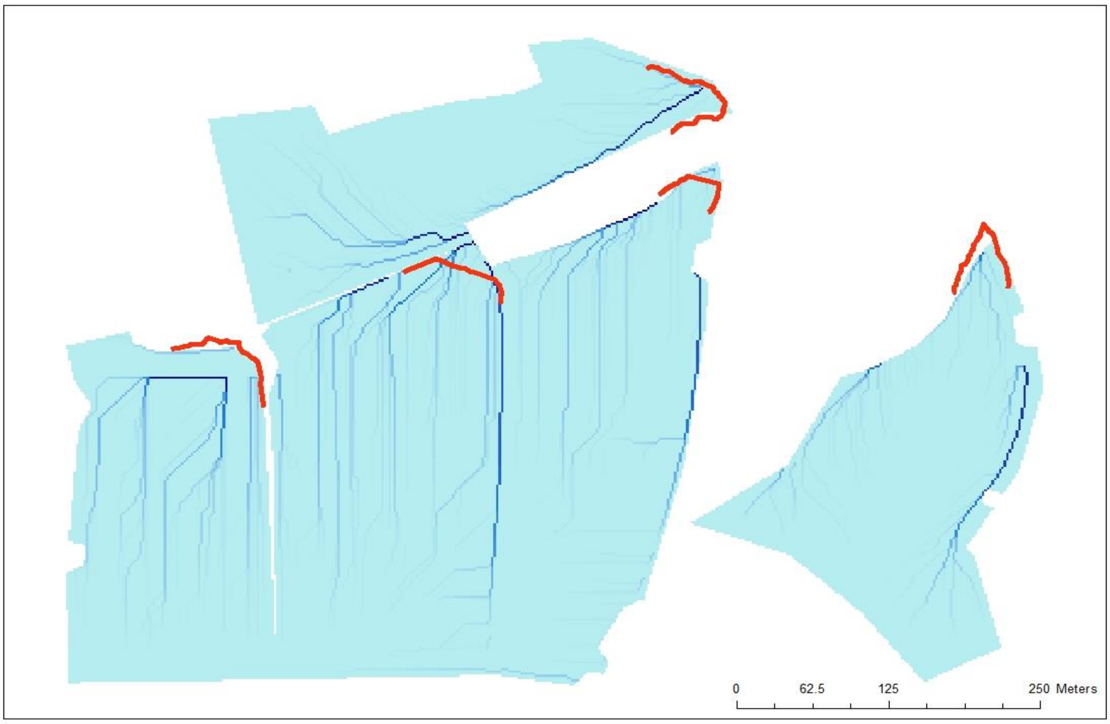


Figure 5.12 Field flow paths and proposed bund locations

Table 5.5 Bund storage capacities and catchment sizes

Field name	Bund storage capacity (m^3)	Catchment size (m^2)	Max Runoff (m^3) per 1mm rainfall
First Sunnydale	62	9331.7	9.3
Second Sunnydale	340	19755.4	19.8
Common Mere	630	49520.5	49.5
Micklebarrow Springfield	866	22531.2	22.5
Parklane Close	322	47084.6	47.1

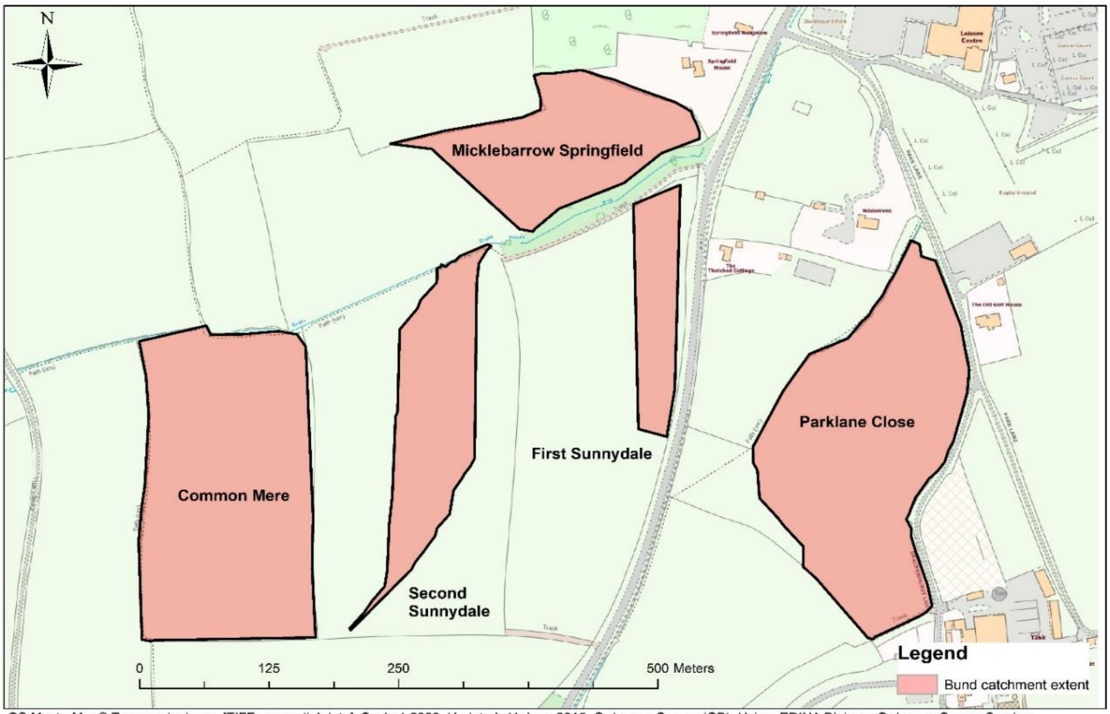


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Figure 5.13 Bund catchment extent. Springfield Dumble catchment is west and has four bunds, Parklane Dumble to the east with one bund.

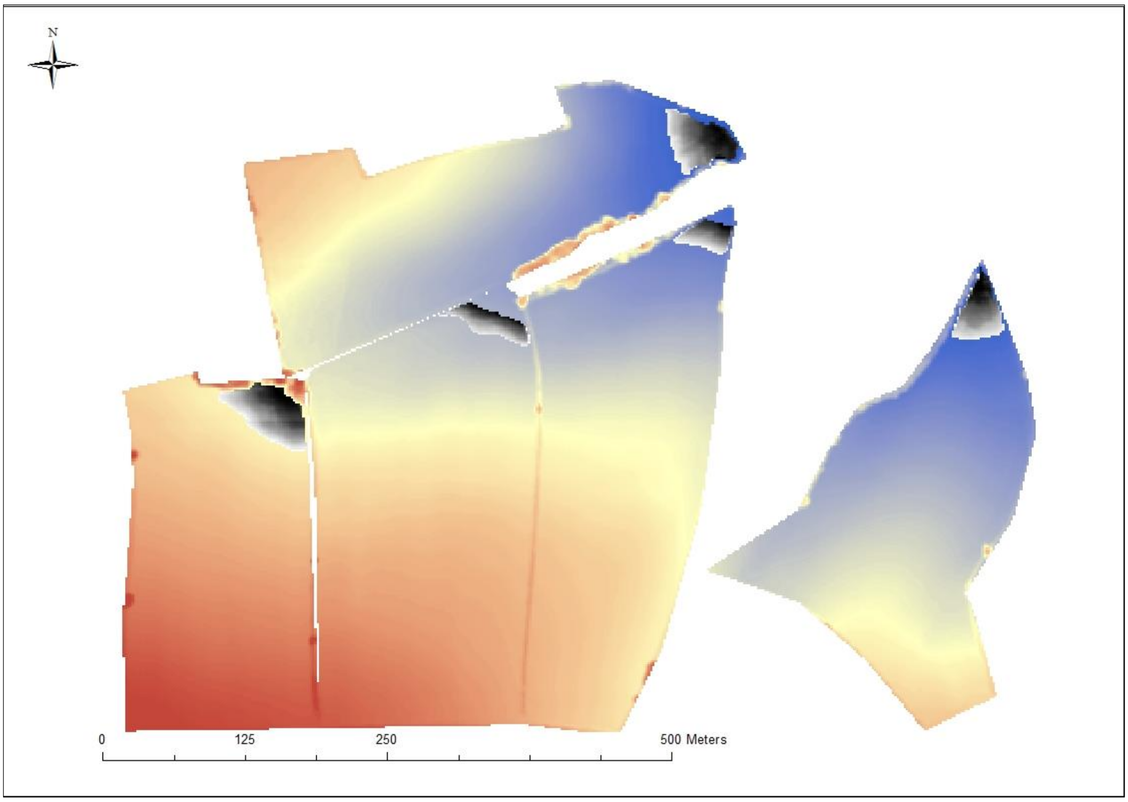

Figure 5.14 Indicative extent of temporary ponding behind proposed bunds. Red shading indicates high ground, blue indicates low ground, black/grey indicates depth of ponding (assuming maximum depth 1m).

Figure 5.15 Common Mere bund after a rainfall event

5.2.2.3 Large Woody Debris (LWD) dams

In total, 13 LWD dams have been installed as part of the NFM interventions within the catchment. As described previously, ten of the LWD dams were installed in June and July 2016, with three more being installed in the Springfield Dumble restoration reach in June 2017. Two phases of installation were required because the excavations for the restoration caused disturbance to the soil, leaving a bare surface. To limit the possibility of erosion, the reach was allowed to revegetate before LWD installation.

Sites were selected in places where the storage potential was greater than usual, such as areas of low floodplain within the channel. For added structural strength, where possible, dams were located upstream of trees so that they could be rested against them to limit movement (Figure 5.16).

The LWD dams were designed to be site specific in length and height, depending on the characteristics of the stream bank at each site but also on the materials available for construction. Dams were spaced apart so that a downstream dam would not flood a dam upstream, as this would limit the storage potential (Addy and Wilkinson, 2017).

Trenches were dug into both sides of the stream bank in order for the logs to be winched into place and then buried to further limit movement (Figure 5.16). A gap was left underneath each dam to allow for low flows to pass unimpeded to limit negative impacts on aquatic ecology. This was approximately 10 cm, based upon base flows from the Lower Springfield Dumble stage logger

(Figure 5.16). Each dam additionally had artificial stakes (fence posts) driven into the streambed directly downstream to resist any movement.

Figure 5.16 Construction of LWD dam 2 within the Springfield Dumble (view from upstream).

Figure 5.17 Completed LWD dam 2 within the Springfield Dumble, showing a gap to allow the passage of low flows (view from upstream).

5.2.3 Hydrological data analysis

5.2.3.1 Stream hydrograph characteristics

Events were selected for analysis based on exceedance of 0.1m stage at the Lower Springfield Dumble (LSD) logger. The LWD dams installed within this research were designed to let flows with a stage lower than 0.1m pass unimpeded, so higher flows were when NFM interventions became active. Event hydrographs were separated from base flow using the point at which discharge started to rise, and ending when discharge reached 10% of the first value. This method was applied to all watercourses.

Peak stage (m), discharge (ls^{-1}), lag time (mins), time to peak (mins), time to recede (mins) and total event duration (mins) were calculated. Either a t test or Mann Whitney U test was used to compare central tendency between pre intervention and post intervention hydrograph parameters, depending on results from a normality test.

In order to calculate celerity of the hydrograph peaks, upstream and downstream logger positions were surveyed using Trimble Geo7x GPS. The watercourse was then digitised in ArcMap using an OS 1 to 2000 map. The post restoration stream on Springfield Dumble was digitised in ArcMap using aerial imagery obtained using an Ebee fixed wing UAV (flown by Dr Ben Clutterbuck). Celerity was then calculated using equation 5.2.

Celerity (ms^{-1}) = distance between loggers (m) / time (seconds)

Equation 5.2

Using hydrograph parameters obtained from the Upper Springfield Dumble (USD) and Lower Springfield Dumble (LSD) logger, the relationship between USD and LSD peak discharge, peak stage, time to peak, time to recede and total event duration were calculated. These were plotted using regression. The results were split by pre and post NFM intervention to assess if any changes in the relationship between USD and LSD were present. This method allows for the USD logger to be treated as a control reach, as no NFM intervention took place upstream of this logger.

5.2.3.2 Calculation of storage in gauged bunds

During the GPS survey which were undertaken to calculate bund volume, the logger ruler was surveyed. This allowed for the volume of the bund, at every 10cm ruler height, to be calculated. From this, a rating curve was created which would allow for discharge into the bund to be determined (Figure 5.18). The difference in height between the base of the ruler (0cm) and the outlet pipe was calculated using an automatic level in order to determine when the bund would begin to discharge with regards to the height on the ruler.

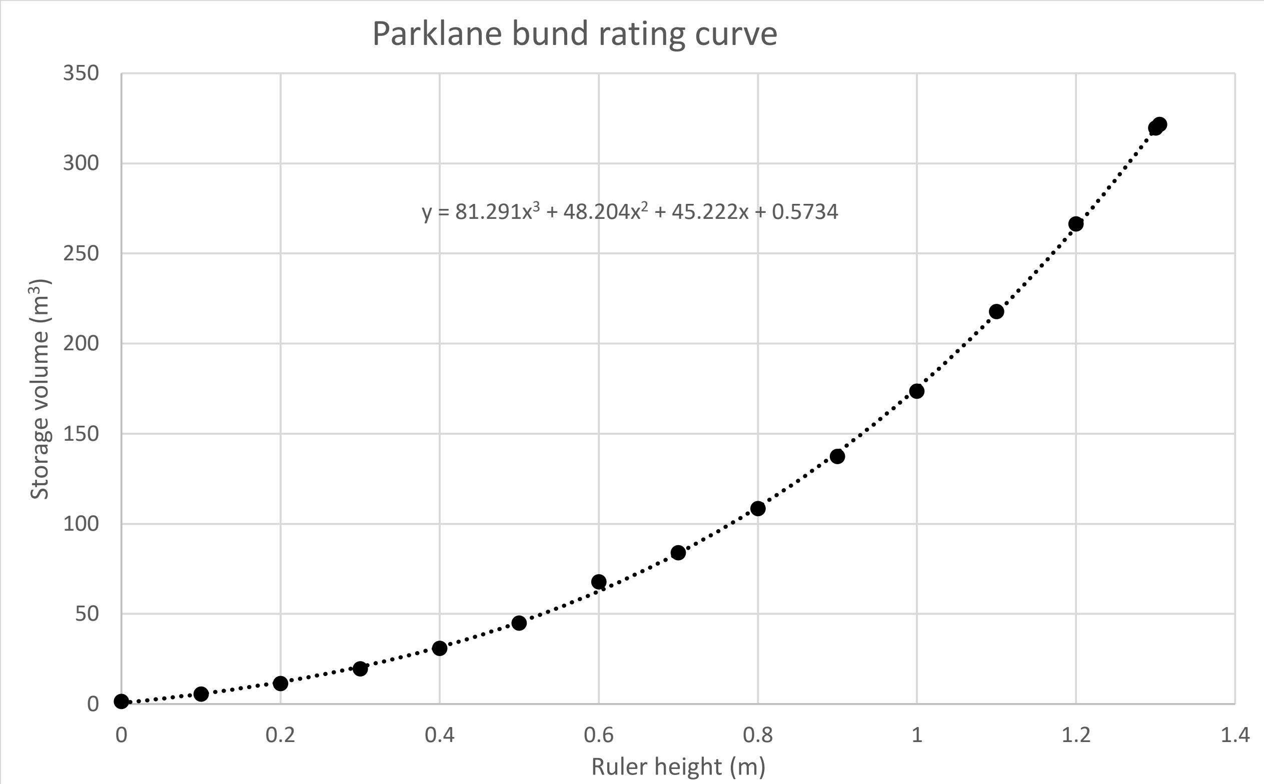

Figure 5.18 An example of a bund rating curve; Parklane bund.

Change in bund storage "fill rate" for bunds with a water level logger within them (Second Sunnydale, Common Mere and Parklane), was calculated for each five minute time step using equation 5.3 from Nicholson (2012). This value is the discharge stored by the bund during each time step.

$$\text{Bund Storage} = Vn - Vn\text{-}1 \,/\, dt = dV/dt$$

Where V is the volume of water within the bund (m^3), n is the time step and t is time (secs)

Equation 5.3

5.2.3.3 Estimation of storage in ungauged bunds

Two of the bunds had no monitoring equipment installed, due to resource constraints, so a method was required to estimate storage over time. Two methods were attempted: using a catchment ratio calculation and rainfall-runoff modelling.

To calculate ungauged bund storage using the catchment ratio method, first the ratio of an ungauged bunds catchment compared to the gauged bunds catchment was calculated. The storage value (ls^{-1}) of a gauged bund was multiplied by the catchment ratio at the corresponding time step to estimate storage within the ungauged bund. Storage values from both Common Mere and 2nd Sunnydale bunds were used to estimate storage in Micklebarrow Springfield and 1st Sunnydale bunds. Ungauged bund outflow was calculated using the equations 5.6-5.9. Table 5.6 shows the ratio values applied to each bund storage data set.

Table 5.6 Catchment ratio values used to calculate storage in ungauged bunds.

Bund name	Catchment area (m2)	Ratio of catchment compared to CM	Ratio of catchment compared to 2nd SD
1st Sunnydale	9331.7	0.19	0.47
2nd Sunnydale	19755.4		
Common Mere	49520.5		2.51
Micklbarrow Springfield	22531.2	0.5	1.14
Parklane	47084.6		

To calculate ungauged bund storage using rainfall-runoff modelling a runoff coefficient was calculated for each event using the gauged bund storage and the rainfall within its catchment to express the amount of rainfall stored during an event by the bund as a percentage (equation 5.4).

$$\textit{Proportion of event rainfall stored by bund} = \Sigma \textit{bund storage } (m^3) / \Sigma \textit{catchment rainfall } (m)$$

Equation 5.4

Equation 5.5 was then used to calculate the discharge stored by the ungauged bund. It allows some consideration of antecedent soil conditions as it is assumed that ungauged bund catchments have similar antecedent conditions to gauged bund catchments. Using the storage percentage, rainfall-runoff modelling was used to estimate the amount of runoff entering the ungauged bunds.

$$Q_{ungauged\ bund} = r_{vol} \ X\ C_{oeff}$$

Where Q = discharge stored (m^3s^{-1}), r_{vol} = rainfall volume (m^3). C_{oeff} = calculated runoff coefficient

Equation 5.5

This method was applied to the Micklebarrow Springfield and 1st Sunnydale bunds using the storage percentage calculated from the Common Mere bund and 2nd Sunnydale bund. It was found that this method created difficulties due to the method of rainfall recording. As each tip represents 0.2mm of rainfall, spikes within the estimated storage were observed after each tip. To prevent this, rainfall data was divided by the previous number of time steps which had no rainfall data recorded. Therefore, there is an assumption that rainfall fell at an even rate between each tip.

Discharge from ungauged bunds was calculated by using a formula based on Bernoulli's equation and set out within Nicholson (2012) (Equation 5.6). This allows for an estimate of Q_{out} of the bund to be represented during filling and draining down of the bund. The following equation was applied.

$$Q_{out} = C\text{d}.a\sqrt{}(2gH)$$

Where Cd is a coefficient of discharge (in this case 0.75 to account for a bevelled orifice).

a is the area of the outlet (m^2)

H is the height if water above the outlet (m)

Equation 5.6

When the outlet pipe of the bund was calculated to be partially submerged the angle between the centre of the partially submerged pipe and the water was determined by

$$\theta=2\cos^{-1}[(D/2-y)/D2] \qquad if\ y<D/2$$

Equation 5.7

$$\theta=2\pi+2\cos^{-1}[(D/2-y)/D2] \quad if\ y>D/2$$

Where y is the depth of water (m) and D is the difference in height between the water level and top of the pipe (m).

Equation 5.8

The effective area of the pipe was then determined by the equation below and the resulting value used to calculate Q_{out} using the equation above (Nicholson 2012).

$$A=(D^2/8)(\theta-\sin\theta)$$

Where A = area of pipe (m^2) and D = depth of water (m)

Equation 5.9

To calculate simulated hydrographs for both methods, bund storage values for each time step were totalled with the observed stream discharge. This gave a calculation of stream discharge if the bund had not been in place and so had not stored runoff during that time step. However, as the loggers are located downstream of the bunds, a delay is needed between the time of storage and the stream discharge measurement, as it would take time for the storage to be realised at the downstream logger. Delay values were estimated by using the length of the stream between bunds and the logger and observed velocity values recorded during flow gauging.

A 10 minute and 15 minute delay between the bund storage and its impact on LSD discharge was applied to the 2nd Sunnydale and Common Mere bunds respectively. When applying storage values to the Potwell Dyke logger, a delay of 15 minutes was applied between the storage values calculated at the LSD logger with 55 minutes delay was applied to the LPD data. Stream length between sites and velocity data obtained from discharge readings during events were used to estimate this.

5.3 Results

5.3.1 Hydrological study data

5.3.1.1 Rainfall data

Nottinghamshire has an annual average rainfall of 709.4 mm (Met Office, 2019). Results from Table 5.7 suggest that Southwell experienced lower than average rainfall during the 2016-17 and 2017-18 hydrological years, in which the post NFM events are recorded. Figures 5.19, 5.20 and 5.21 show the hourly rainfall recorded during each hydrological year. Three events were recorded with a 60 minute rainfall greater than 9mm/hr. Although below average annual rainfall has been observed in the period post NFM intervention, the two events (2/4/18 and 10/4/18) with the greatest peak discharge recorded both took place after NFM intervention.

Table 5.7 Total annual rainfall at Brackenhurst (Southwell) for each hydrological year.

Hydrological year	Total annual rainfall (mm)
2015-16	652.8
2016-17	525.4
2017-18	473.0

Note: Data are missing for Casella raingauge between 1/9/17 and 15/11/17. Data from the Adcon raingauge have been used for this period.

Rainfall data from analysed events are shown in Table 5.8. Pre NFM intervention, the 21/11/16 event had the greatest total rainfall with 30.6mm recorded. Post NFM intervention, the greatest total event rainfall occurred during the 10/4/18 event with 18.6mm recorded. Both of these events were not of a magnitude to cause flooding within Southwell. However, the greatest discharge of the Potwell Dyke pre and post NFM, was recorded as a result of these rainfall events.

Intensity of the rainfall is an important characteristic of the rainfall event. A pre intervention 60 minute intensity of 10.4mm.hr^{-1} was recorded on the 21/11/16. However, the 14/6/16 event had a 60 minute intensity of 11.4mm.hr^{-1}. Post NFM intervention, the 10/4/18 event has a 60 minute intensity of 3.2mm.hr^{-1}. However, the 02/06/18 event was recorded at 10.4mm.hr^{-1}.

Sampled events were calculated to have low return periods when using the max 60 minute rainfall data (Table 5.8). The 14/6/16 event is calculated to have the highest return period of 1.74 using the FEH 2013 return period. However, the highest peak discharges were recorded at a result of the rainfall on the 2/4/18 and 10/4/18 (Table 5.10).

Table 5.8 Rainfall data from events analysed

Date	Magnitude (total mm rainfall)	Max 60 min intensity (mm.60mins^{-1})	Max clock hour intensity (mm.hr^{-1})	FEH 2013 60 min return period (using annual maximum series)	FEH 2013 60 min return period (Peaks over threshold)	FEH 1999 60 min return period (using annual maximum series)	FEH 1999 60 min return period (Peaks over threshold)
12/12/2015	13	3.2	3.2	N/A		1	0
30/12/2015	8.8	2	1.6	N/A		1	0
03/01/2016	6.8	2	2	N/A		1	0
07/01/2016	13.4	3.6	2.8	N/A		1	0
05/02/2016	14.2	2.2	2.2	N/A		1	0
17/02/2016	11	1.2	1	N/A		1	0
03/03/2016	9	3	2.8	N/A		1	0
09/03/2016	18.8	4.6	4.4	N/A		1	0.06
28/03/2016	14.6	4.2	3.8	N/A		1	0.04
15/04/2016	12	1.8	2.6	N/A		1	0
14/06/2016	18.8	11.4	9.4	1.74	1.17	1.66	1.09
29/06/2016	18.2	9	5.4	1.37	0.76	1.16	0.5
21/11/2016	30.6	10.4	7.4	1.56	0.98	1.41	0.81
06/02/2017	5.2	1.8	1.4	N/A		1	0
27/09/2017	12.4	2	1.8	N/A		1	0
25/12/2017	7.8	3.2	3	N/A		1	0
26/12/2017	10.2	1.2	1.2	N/A		1	0
30/12/2017	7.8	3.6	3	N/A		1	0
05/01/2018	7	3	2.8	N/A		1	0
09/03/2018	8.8	2	1.6	N/A		1	0
11/03/2018	17.6	2.8	2.4	N/A		1	0
30/03/2018	15.2	3.6	2.8	N/A		1	0
31/03/2018	15.2	2.8	2.4	N/A		1	0
02/04/2018	15.4	2.6	2.2	N/A		1	0
03/04/2018	7.6	2.4	2.2	N/A		1	0
10/04/2018	18.6	3.2	2	N/A		1	0
12/04/2018	6.2	2	0.8	N/A		1	0
02/06/2018	12.6	10.4	9.2	1.56	0.98	1.41	0.81

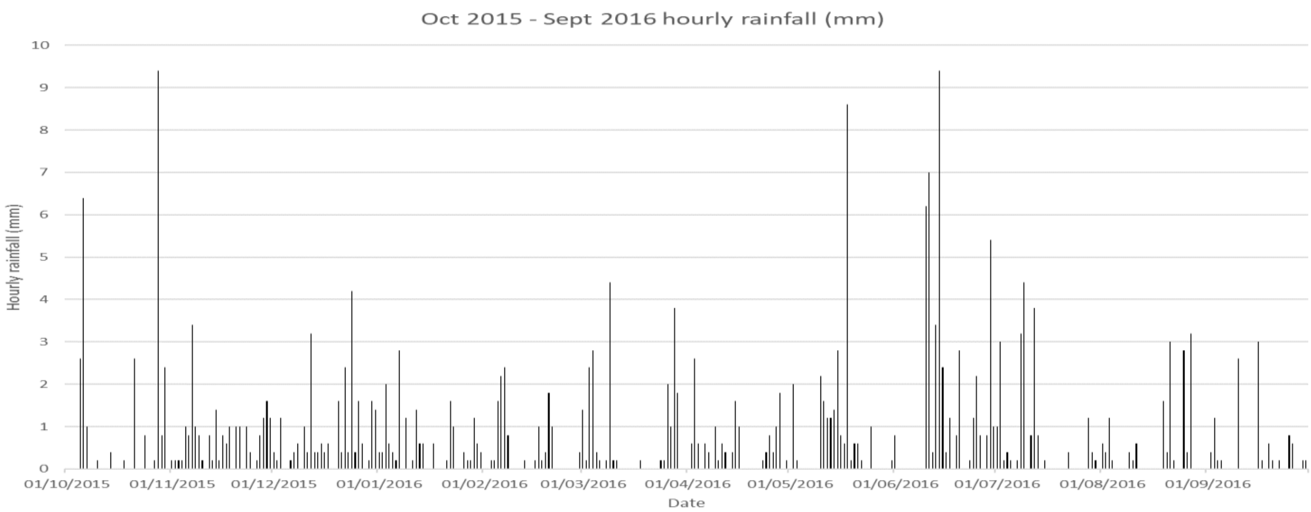

Figure 5.19 Hourly rainfall recorded between October 2015 and September 2016.

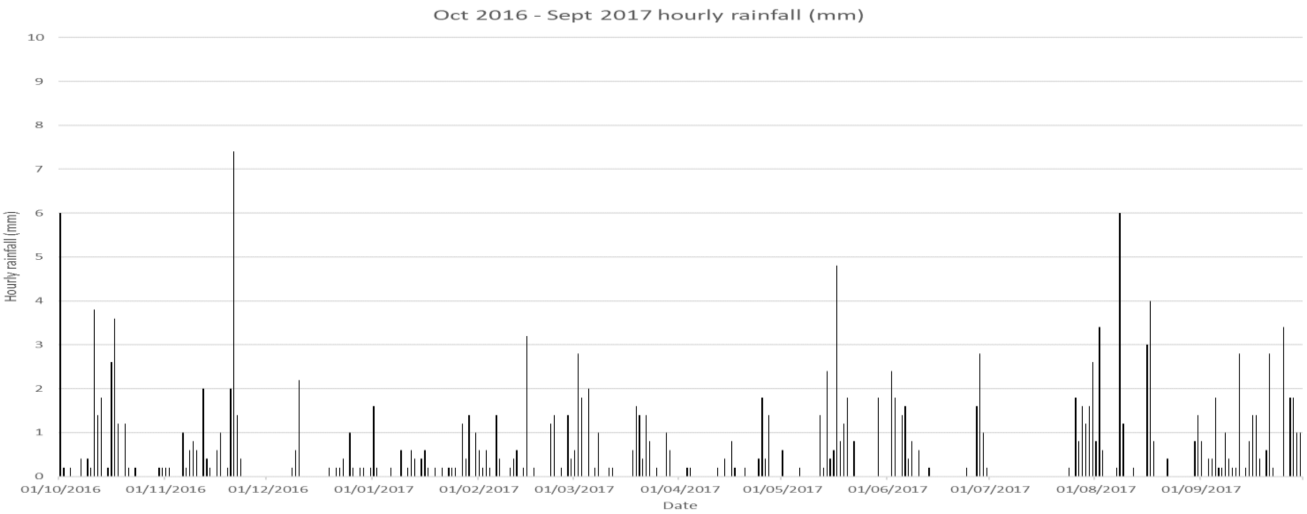

Figure 5.20 Hourly rainfall recorded between October 2016 and September 2017.

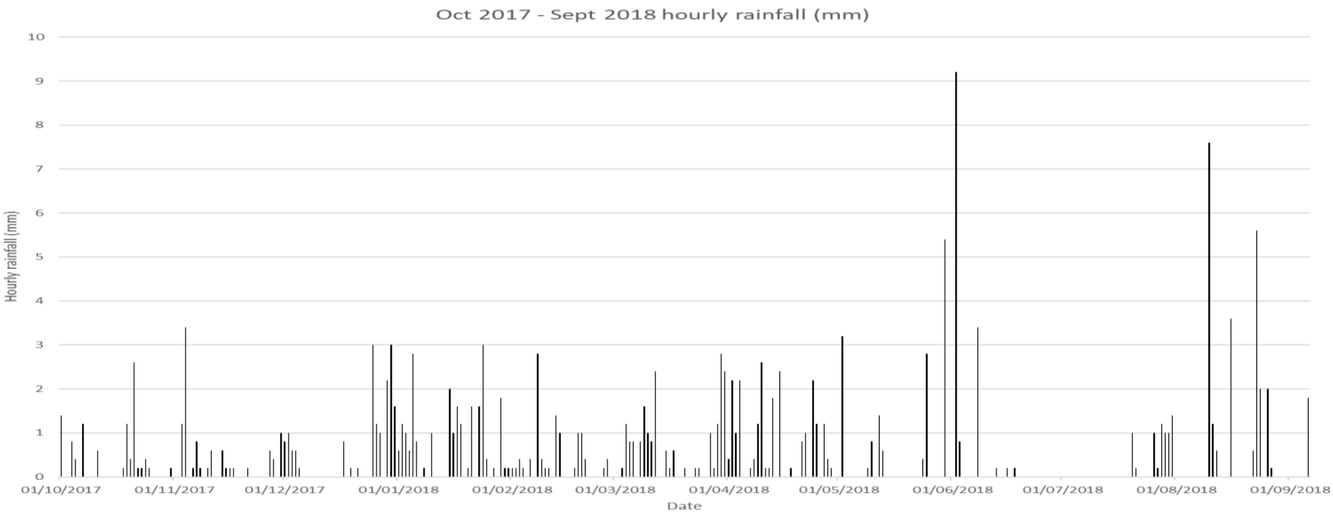

Figure 5.21 Hourly rainfall recorded between October 2017 and September 2018.

5.3.1.2 Stream discharge

From the recorded stage at each logger site, discharge was calculated using rating curves shown in Figures 5.22- 5.25. For Lower Parklane Dumble (LPD), sedimentation occurred on the 21/3/17 and so a new rating curve was developed.

Figures 5.26, 5.27 and 5.28 show discharge recorded at Lower Springfield Dumble (LSD). Base flow is typically within the range of 5.5-6 ls^{-1}. Pre NFM intervention, 12 events were recorded with a discharge > 23.3 ls^{-1} (10cm stage) at the LSD logger. Post intervention, 16 events were recorded with discharge > 23.3 ls^{-1} at the LSD logger. The maximum discharge recorded pre intervention was 347ls^{-1} recorded during the 21/11/16 event. A discharge of 182 ls^{-1} was recorded during the 9/3/16 event. The maximum discharge recorded post intervention was 527 ls^{-1} on the 1/4/18, with 459 ls^{-1} recorded during the 10/4/18 event.

The Parklane Dumble is dry throughout most of the year having no or very little base flow (Figures 5.29, 5.30 and 5.31). During the 2016-17 and 2017-18 periods, the Parklane Dumble is observed to be dry throughout the summer months, only flowing after prolonged rainfall. The maximum discharge recorded pre intervention was 160ls^{-1} on the 9/3/16 with a maximum of 157 ls^{-1} being recorded post intervention during the 30/12/17 event. The early April events of 2018 discussed above did not cause such a rise in discharge at LPD as occurred at LSD.

Discharge for the Potwell Dyke at Park Lodge is shown in Figures 5.32, 5.33 and 5.34. Base flow is observed to typically be in the range of 20 –35 ls^{-1}. The maximum discharge recorded pre intervention was 2178 ls^{-1} on the 21/11/17 with 1703 ls^{-1} recorded on the 9/3/16. A post intervention maximum discharge of 2161 ls^{-1} was recorded at Park Lodge during both the 2/4/18 and 10/4/18 events. The median annual maximum flow for the Potwell Dyke at Park Lodge is 0.85m^3s^{-1}.

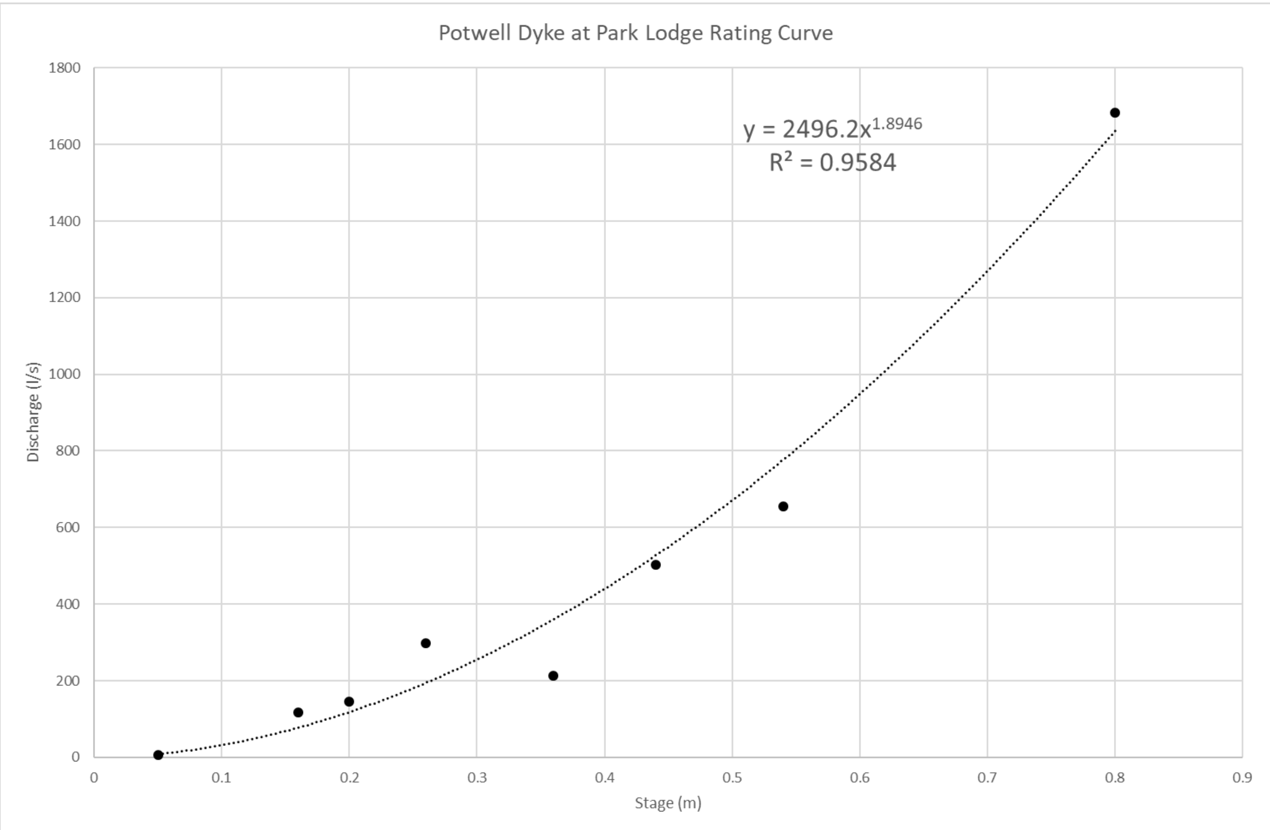

Figure 5.22 Potwell Dyke at Park Lodge rating curve October 2015 – March 2016.

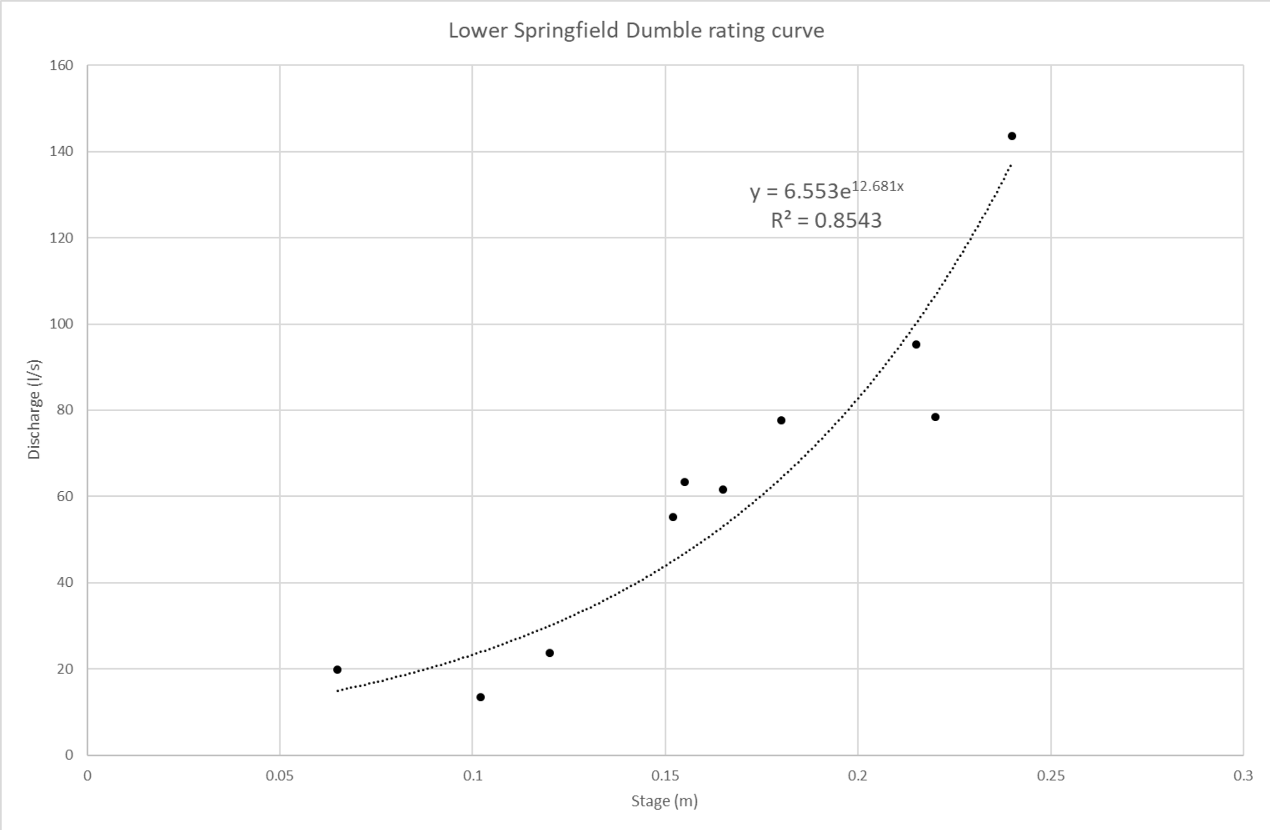

Figure 5.23 Lower Springfield Dumble rating curve March 2016 – March 2018.

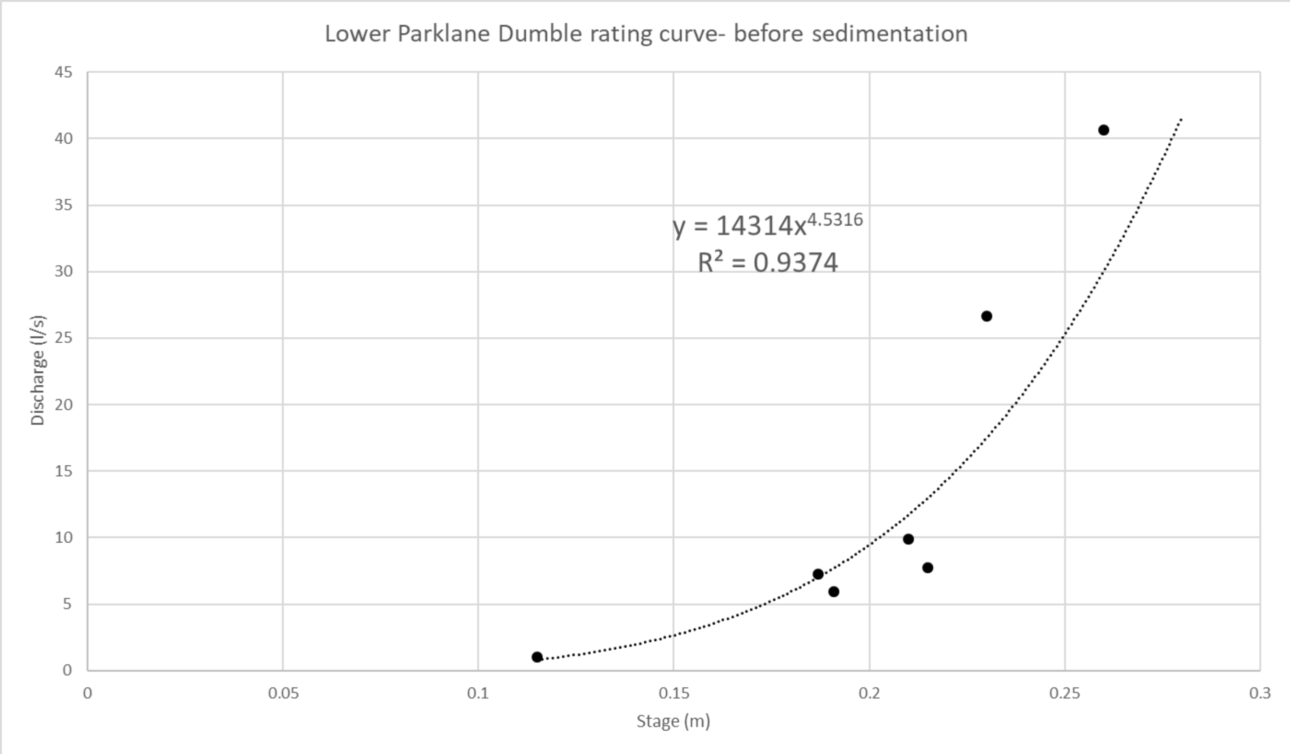

Figure 5.24 Lower Parklane Dumble rating curve before sedimentation March 2016- 21/3/17.

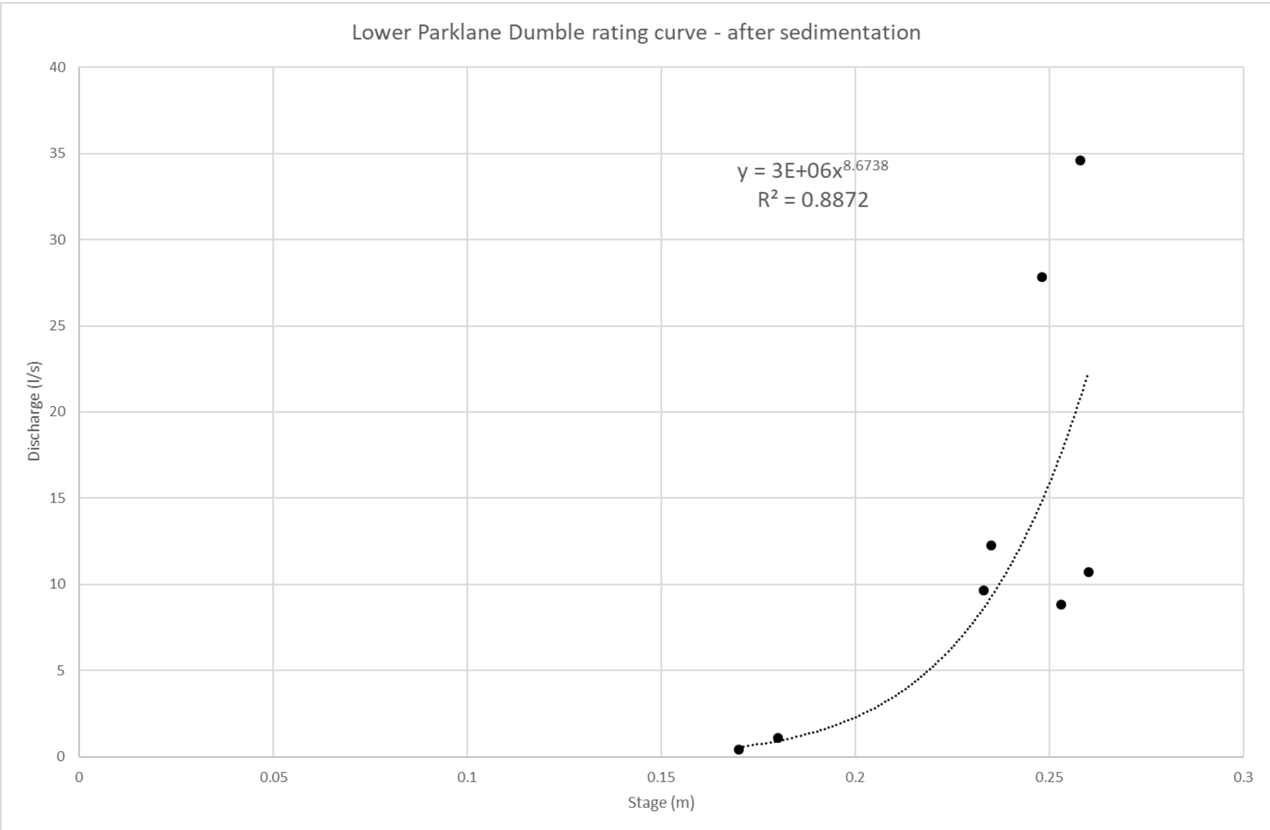

Figure 5.25 Lower Parklane Dumble rating curve after sedimentation 21/3/17- March 2018.

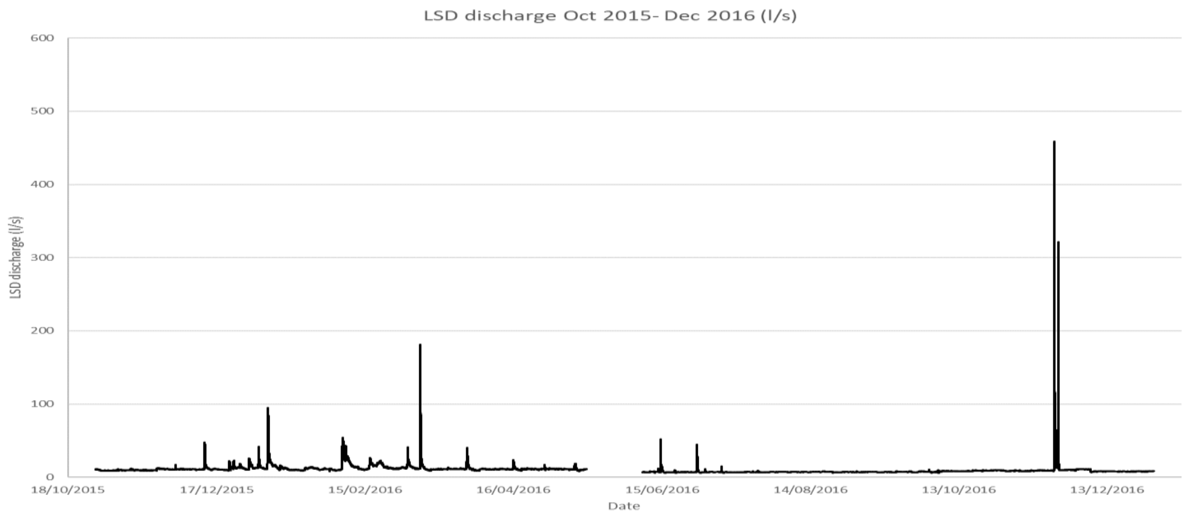

Figure 5.26 Lower Springfield Dumble discharge from October 2015 - December 2016. Data are missing between 15/5/16 and 9/6/16 due to logger memory failure.

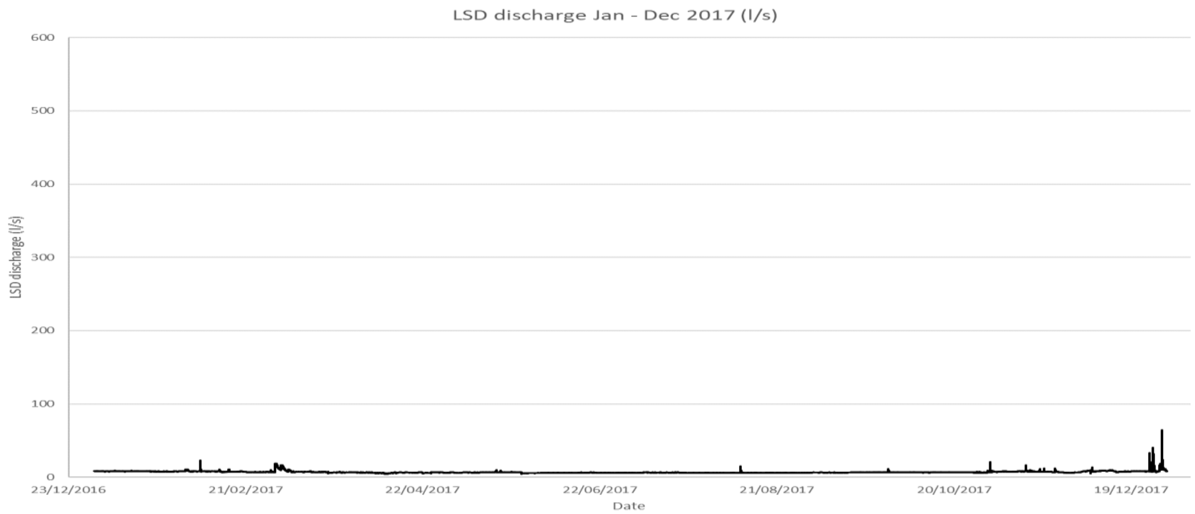

Figure 5.27 Lower Springfield Dumble discharge from January – December 2017.

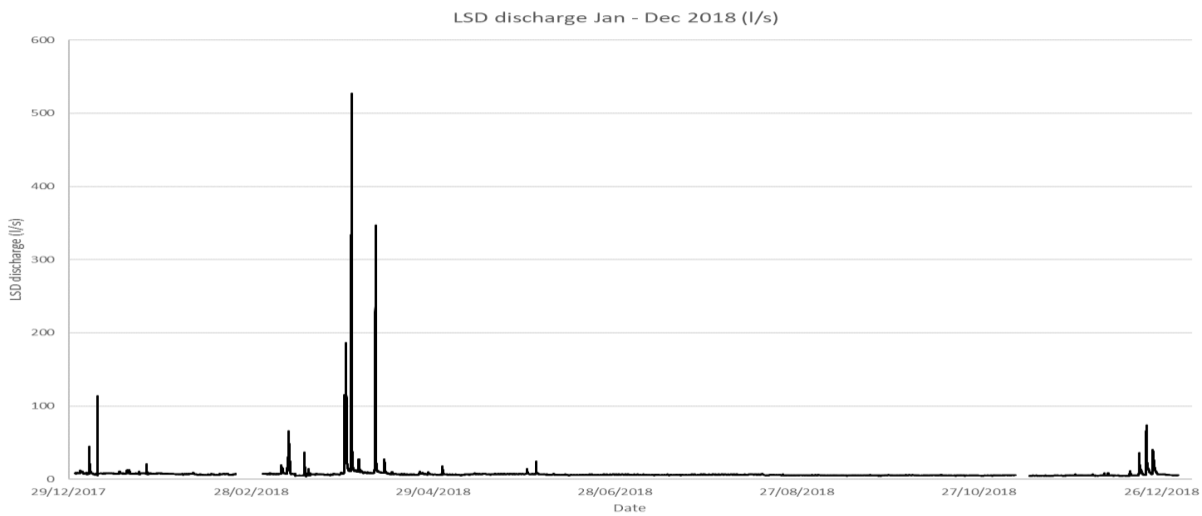

Figure 5.28 Lower Springfield Dumble discharge from January – December 2018. Data are missing between 22/2/18 – 3/3/18 and 7/11/18 – 14/11/18 due to logger failure.

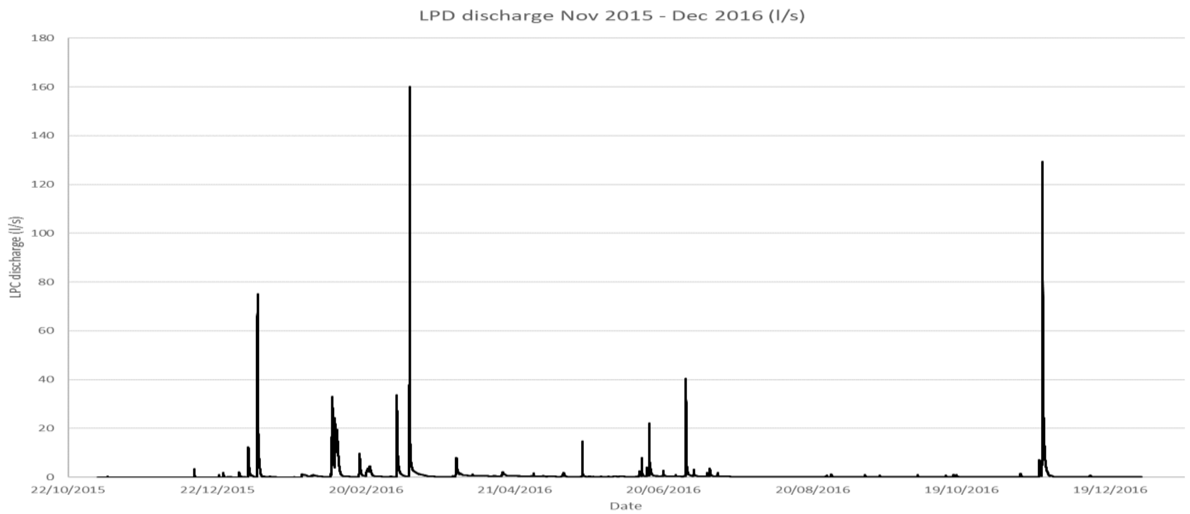

Figure 5.29 Lower Parklane Dumble discharge from November 2015 - December 2016.

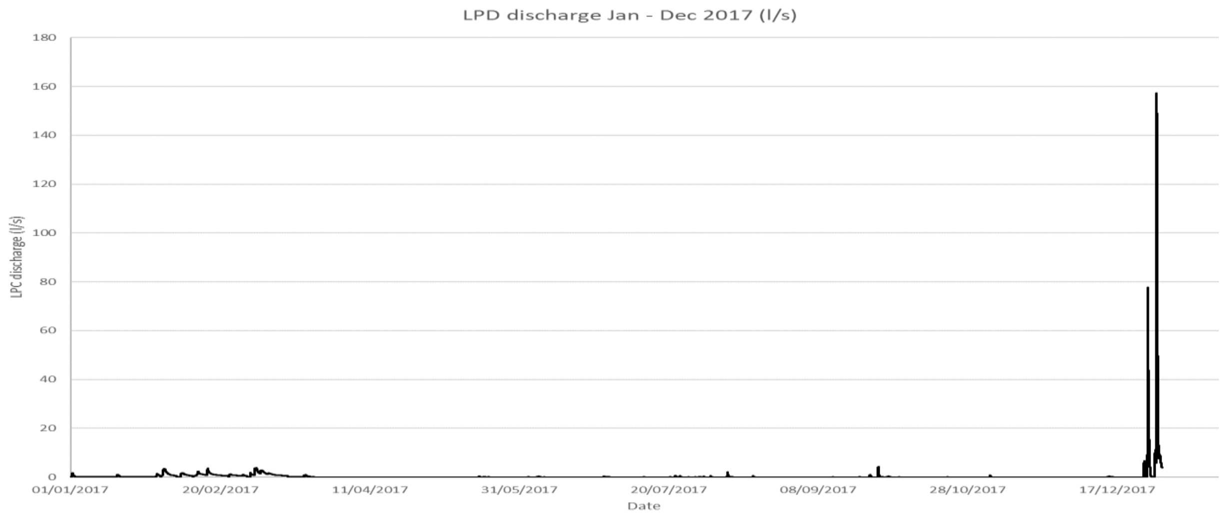

Figure 5.30 Lower Parklane Dumble discharge from January – December 2017.

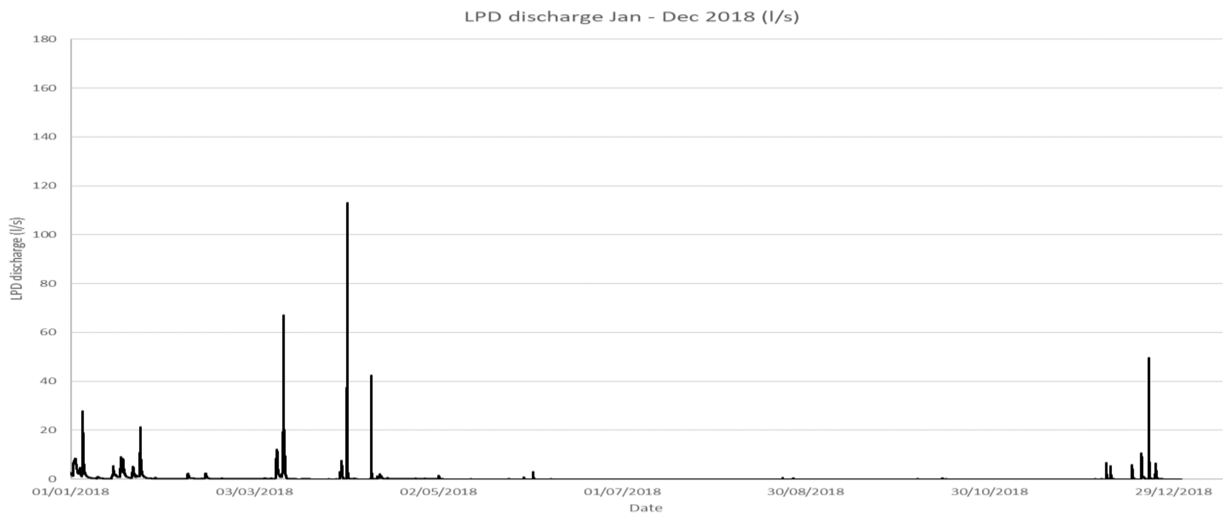

Figure 5.31 Lower Parklane Dumble discharge from January – December 2018.

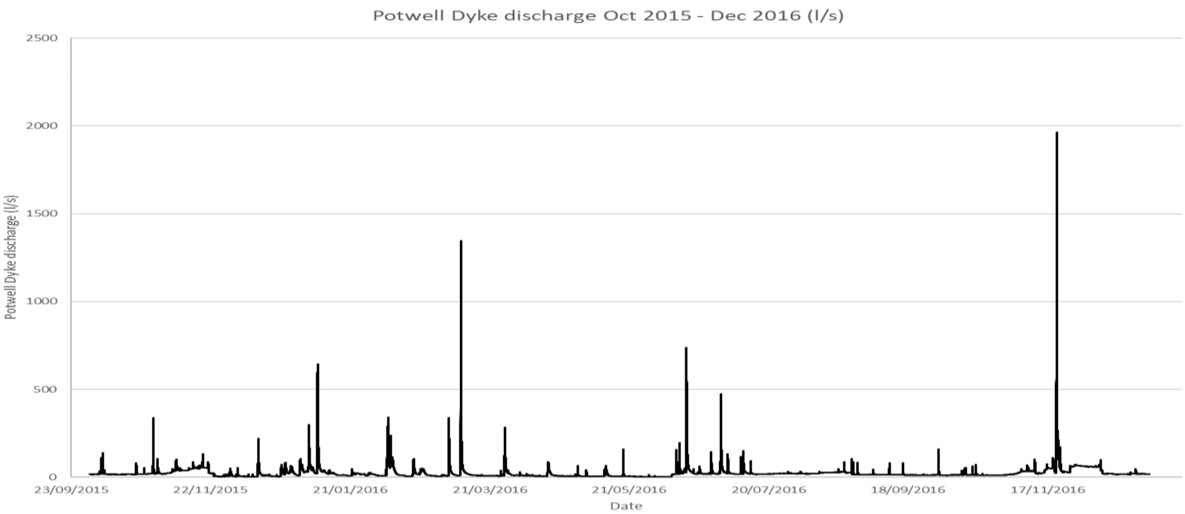

Figure 5.32 Potwell Dyke at Park Lodge discharge from October 2015 – December 2016.

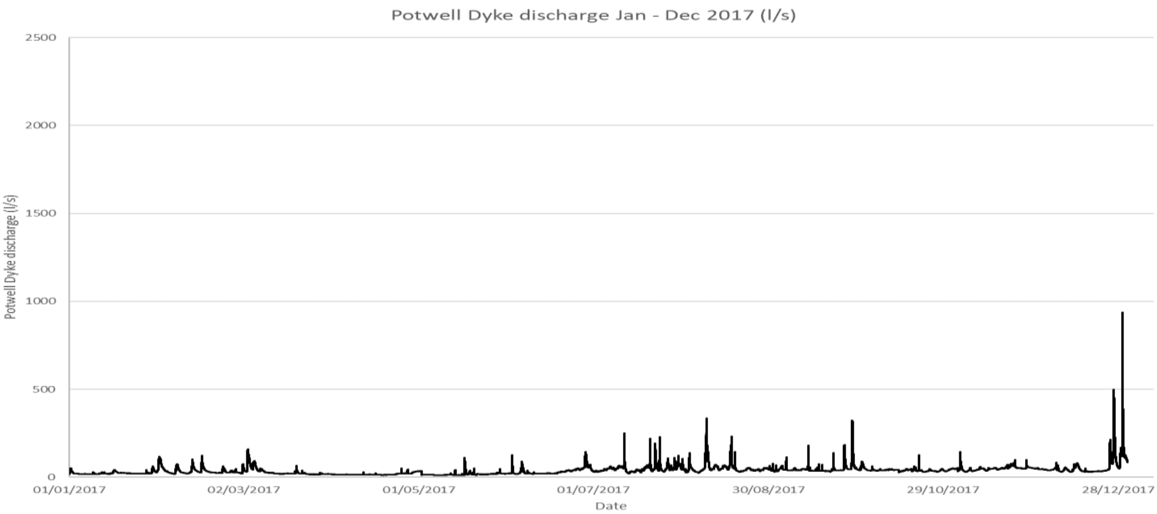

Figure 5.33 Potwell Dyke at Park Lodge discharge from January – December 2017.

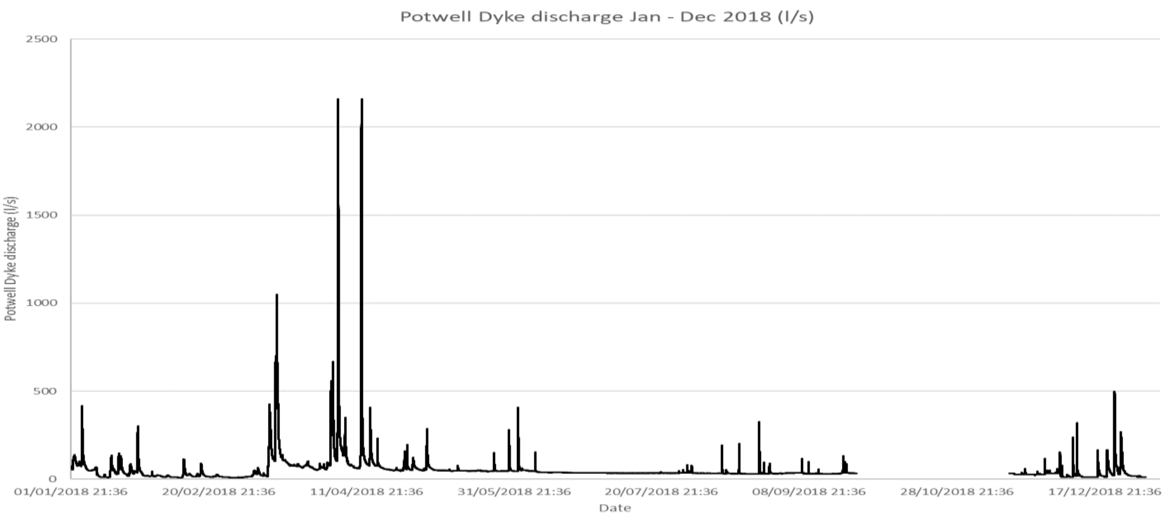

Figure 5.34 Potwell Dyke at Park Lodge discharge from January – December 2018. Data are missing between 25/9/18 - 15/11/18 due to logger battery failure.

Table 5.9 shows event hydrograph parameters obtained from flow events where LSD peak stage exceeded 10cm (23.3ls^{-1}). The mean pre intervention lag time for LSD, LPD and the Potwell Dyke (Park Lodge), were 148 mins, 218 mins 244 mins respectively (Table 5.9). These ranged between 31-292 mins, 23 -582 mins and 68-477 mins. Peak discharge pre intervention for LSD, LPD and Potwell Dyke (Park Lodge) had a mean of 84ls^{-1}, 40 ls^{-1} and 572 ls^{-1} respectively. These ranged between 24-459 ls^{-1}, 2-160 ls^{-1} and 86- 2178 ls^{-1}.

Post intervention average lag times for LSD, LPD and the Potwell Dyke (Park Lodge) are, 126 mins, 140 mins and 220 mins respectively. Lag times ranged between 55-303 mins, -8 – 393 mins and 95-783 mins. Peak discharge post intervention for LSD, LPD and Potwell Dyke (Park Lodge) had a mean of 110ls^{-1}, 34 ls^{-1} and 688 ls^{-1} respectively. These ranged between 19-527 ls^{-1}, 1-157 ls^{-1} and 73- 2161 ls^{-1}.

Table 5.9 Hydrograph parameter statistics where LSD stage > 10cm

	Lag time mean (mins)	**Lag time range (mins)**	**Peak discharge mean (ls^{-1})**	**Peak discharge range (ls^{-1})**
Pre Intervention				
LSD	148	31-292	84	24-459
LPD	218	23-582	40	2-160
PD	244	68-477	572	86-2178
Post Intervention				
LSD	126	55-303	110	19-527
LPD	140	-8–393	34	1-157
PD	220	95-783	688	73-2161

Table 5.10 Hydrograph parameters for flow events analysed based on exceeding 10cm at the Lower Springfield Dumble Logger. Pre and post NFM intervention events are split by the solid line.

Event start date	LSD peak stage (m)	LSD peak Q (l/s)	LSD lag time (mins)	LPD peak stage (m)	LPD peak Q (l/s)	LPD lag time (mins)	PD peak stage (m)	PD peak Q (l/s)	PD lag time (mins)
12/12/2015	0.156	47	111	0.159	3	40	0.277	217	112
30/12/2015	0.108	26	259	0.142	2	430	0.187	103	477
03/01/2016	0.146	42	205	0.211	12	251	0.326	296	343
07/01/2016	0.186	69	106	0.314	75	442	0.489	637	434
05/02/2016	0.148	43	112	0.225	17	104	0.32	285	137
17/02/2016	0.111	27	238	0.2	10	305	0.186	102	283
03/03/2016	0.145	41	154	0.263	34	125	0.348	334	171
09/03/2016	0.262	182	126	0.371	160	287	0.822	1703	333
28/03/2016	0.143	40	128	0.192	8	103	0.317	280	135
15/04/2016	0.101	24	292	0.143	2	582	0.17	86	424
14/06/2016	0.163	52	110	0.24	22	110	0.528	737	134
29/06/2016	0.152	45	52	0.273	40	27	0.419	475	121
21/11/2016	0.335	459	31	0.354	129	23	0.936	2178	68
06/02/2017	0.100	23	246	0.137	2	393	0.156	73	783
27/09/2017	0.219	105	147	0.212	4	182	0.341	322	177
25/12/2017	0.128	33	154	0.219	6	55	0.275	214	199
26/12/2017	0.144	41	-	0.296	78	-	0.429	497	-
30/12/2017	0.180	64	74	0.321	157	116	0.6	938	134
05/01/2018	0.147	42	120	0.263	28	160	0.391	417	161
09/03/2018	0.084	19	91	0.231	9	347	0.175	91	307
11/03/2018	0.182	66	117	0.291	67	60	0.636	1048	120
30/03/2018	0.226	115	105	0.186	1	80	0.456	558	275
31/03/2018	0.263	184	70	0.226	7	95	0.502	669	110
01/04/2018	0.346	527	130	0.291	67	165	0.932	2161	170
03/04/2018	0.113	27	303	0.155	-	298	0.356	349	318
10/04/2018	0.313	347	55	0.276	42	15	0.932	2161	110
12/04/2018	0.113	27	91	0.194	2	-8	0.387	409	121
02/06/2018	0.104	25	64	0.204	3	4	0.387	409	95

5.3.1.3 Stream event hydrographs

An example pre intervention event hydrograph from the 9/3/16 event is shown for LSD, LPD and PD in Figures 5.35 and 5.36. A peak rainfall intensity of 4.4 mm.hr^{-1} was observed with an event total of 18.8mm. LSD and LPD had a recorded peak discharge of 181.7 ls^{-1} and 160.1 ls^{-1} with lag times of 126 mins and 287 mins respectively. For the Potwell Dyke, a lag time of 333 mins was recorded and a peak discharge of 1682.6 ls^{-1}.

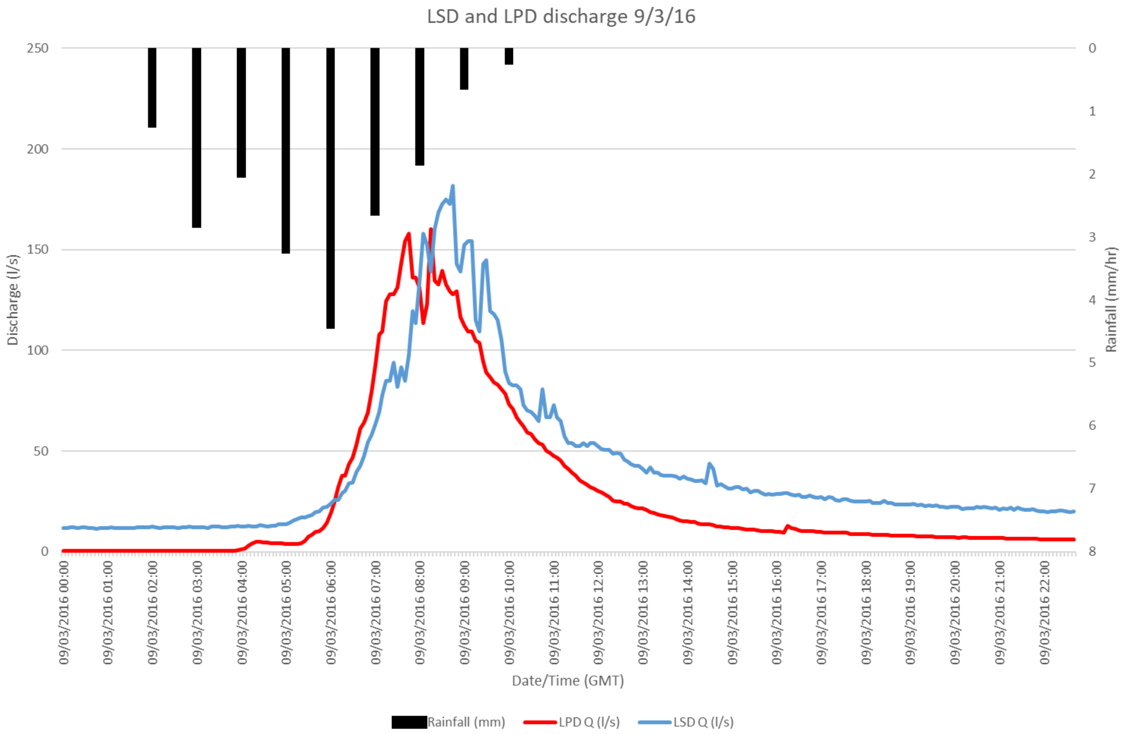

Figure 5.35 Lower Springfield Dumble and Lower Parkland Dumble discharge 9/3/16 (pre intervention).

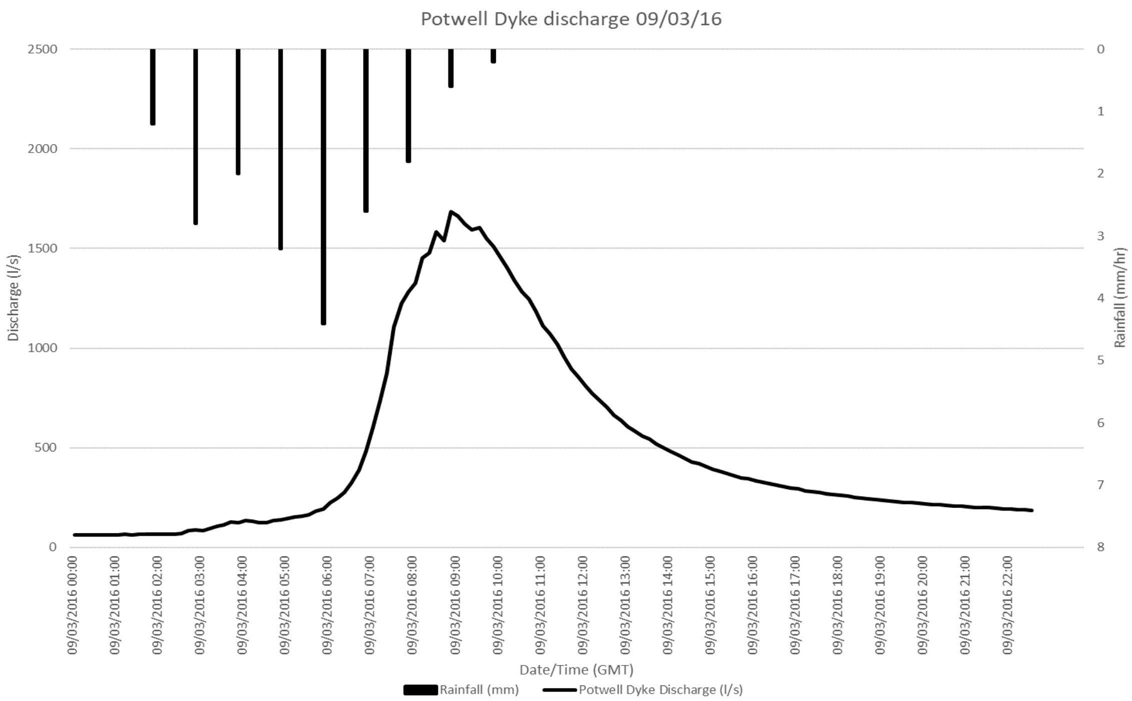

Figure 5.36 Potwell Dyke discharge 9/3/16 (pre intervention).

Example post intervention hydrographs for LSD, LPD and PD, from the 2/4/18 event, are shown in Figures 5.37 and 5.38. A peak rainfall intensity of 2.2 mm.hr^{-1} was observed with an event total of 15.4mm. LSD and LPD had a recorded peak discharge of 527.2 ls^{-1} and 113.0 ls^{-1} with lag times of 130 mins and 165 mins respectively. At the Potwell Dyke, a peak discharge of 2160.9 ls^{-1} and lag time of 170 mins was recorded.

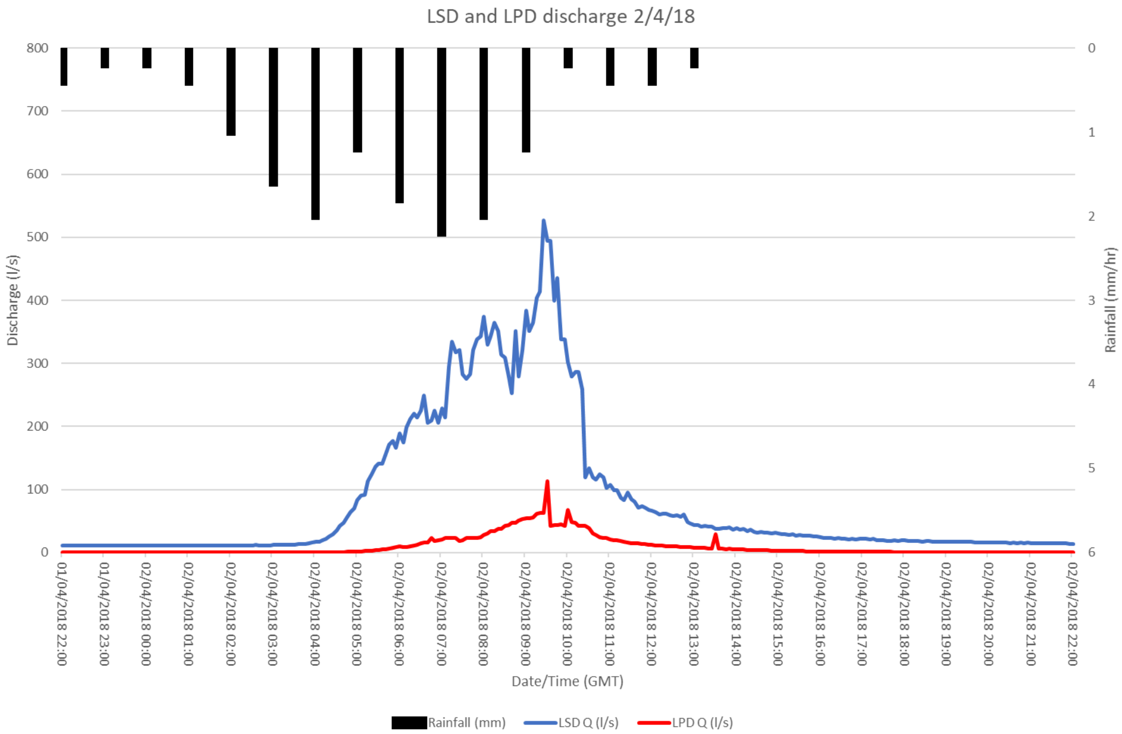

Figure 5.37 Lower Springfield Dumble and Lower Parklane Dumble discharge 2/4/18 (post intervention).

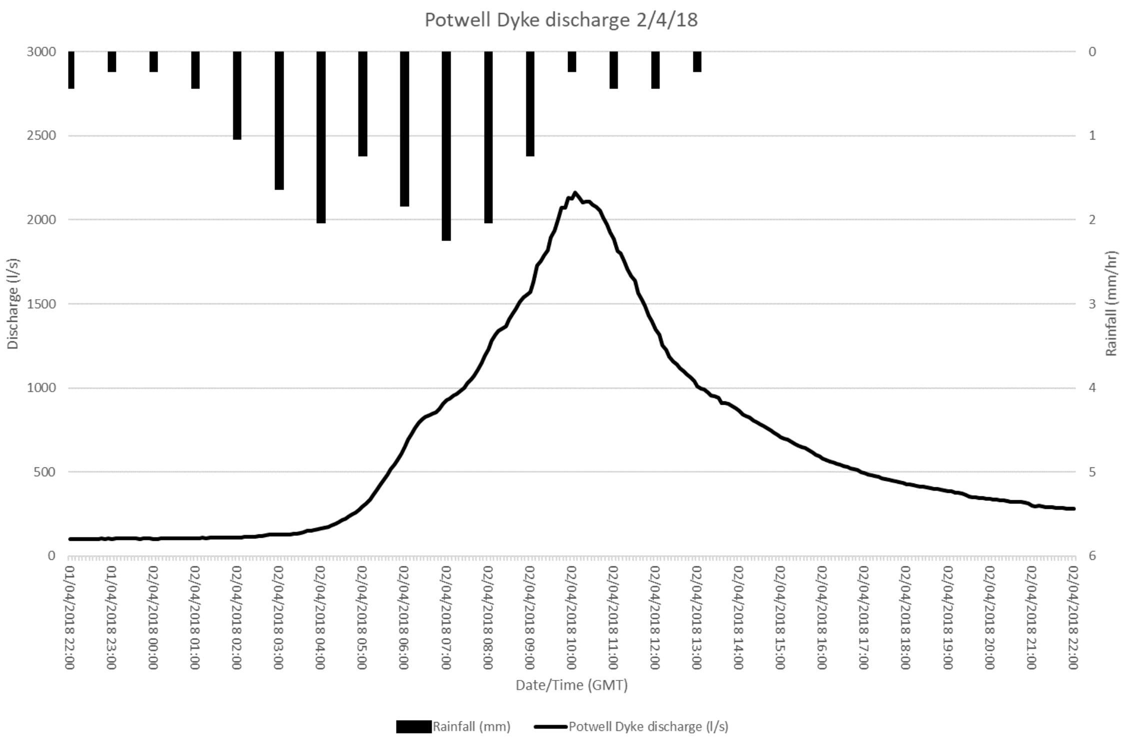

Figure 5.38 Potwell Dyke discharge 2/4/18 (post intervention).

Another example of a large event occurred on the 10/4/18. Post intervention hydrographs for LSD, LPD and PD are shown in Figures 5.39 and 5.40. A peak rainfall intensity of 2.6 $mm.hr^{-1}$ was observed with an event total of 18.6mm. LSD and LPD had a recorded peak discharge of 346.9 ls^{-1} and 17.9 ls^{-1} with lag times of 55 mins and 15 mins respectively. For the Potwell Dyke, a peak discharge of 2160.9 ls^{-1} and lag time of 110 mins was recorded.

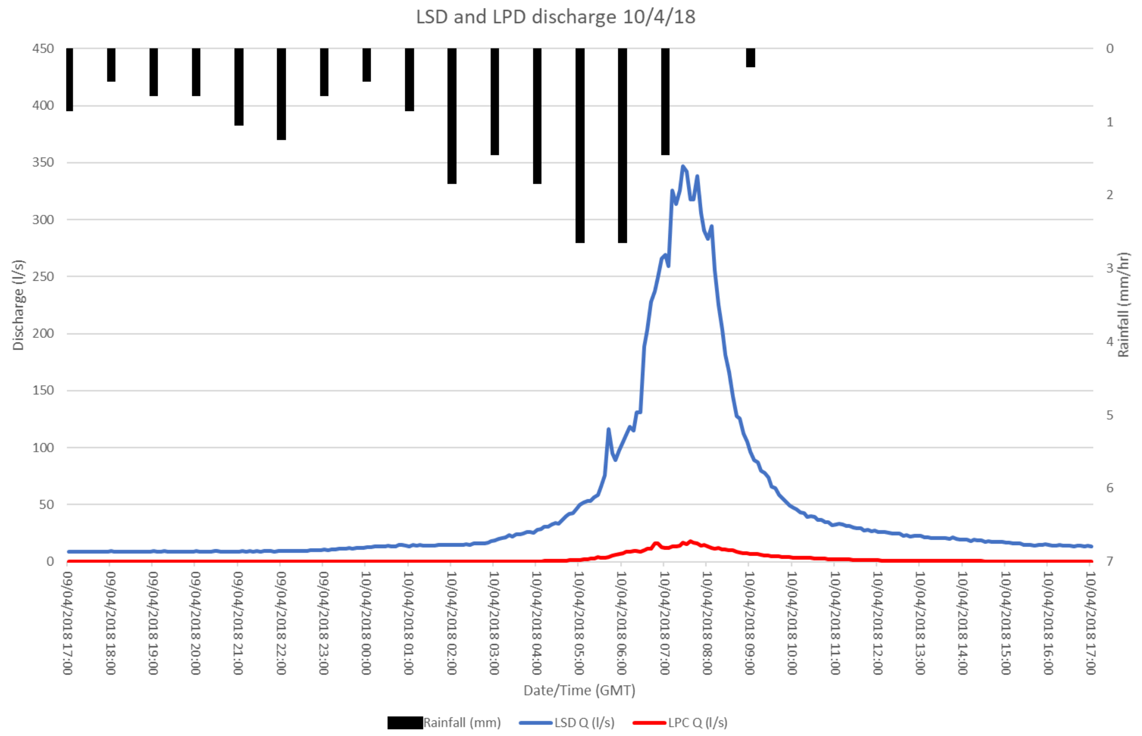

Figure 5.39 Lower Springfield Dumble and Lower Parkland Dumble discharge 10/4/18 (post intervention).

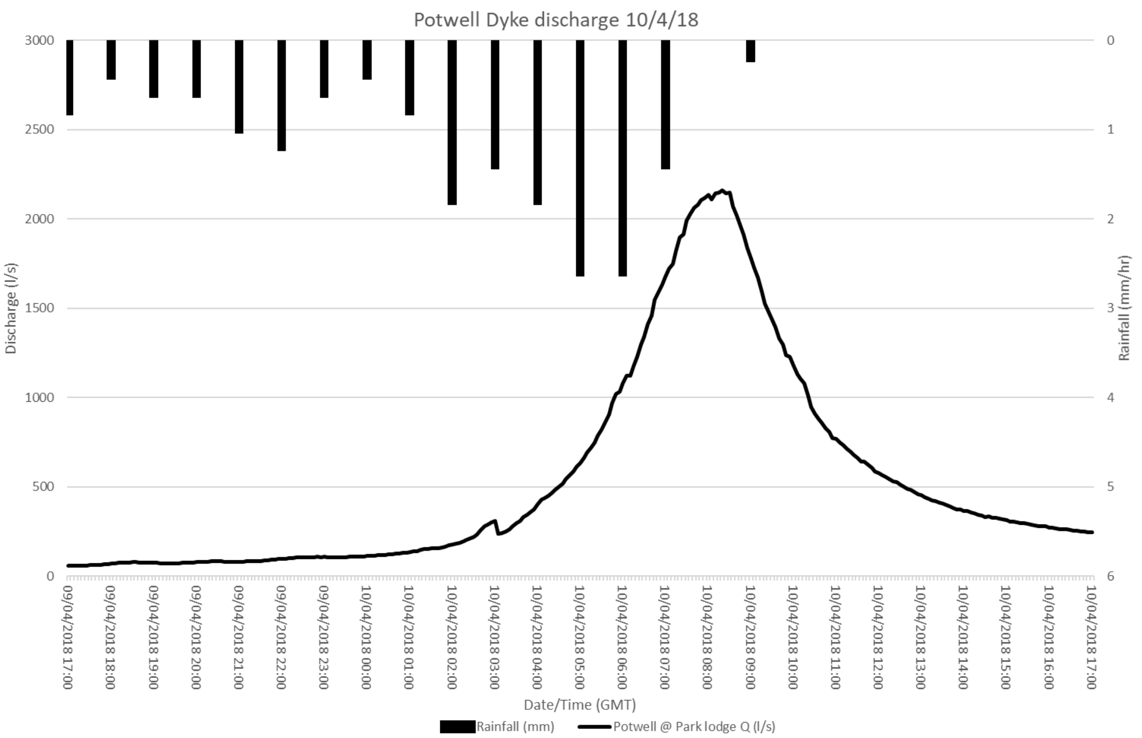

Figure 5.40 Potwell Dyke discharge 10/4/18 (post intervention).

5.3.2 Stream hydrograph parameter changes

The relationship in peak stage between the Upper Springfield Dumble and the Lower Springfield Dumble, pre and post NFM intervention, is shown in Figure 5.41. Results show that the relationship in peak stage between the loggers has changed post NFM intervention. Post intervention, LSD peak stage is observed to be lower for a given stage at USD. For example, during the pre-intervention event on the 9th of March 2016, a peak stage at USD of 0.29m corresponded with a peak stage at LSD of 0.262m. Using the post intervention equation in Figure 5.41, a post NFM peak stage of the same magnitude at the USD logger, would result in an estimated peak stage of 0.10m at LSD when using the post intervention regression curve. This represents a reduction in discharge from 182 ls^{-1} to 23.3 ls^{-1} when using the rating curve in Figure 5.23.

For another example during the pre-intervention event on the 21st of November 2016, a peak stage of 0.368m at USD and 0.335m at LSD was recorded. Using the same method, a post NFM peak stage of the same magnitude at the USD logger, would result in an estimated peak stage of 0.18m at LSD post intervention. This represents a reduction in discharge from 458 ls^{-1} to 71.3 ls^{-1} when using the rating curve in Figure 5.23. However, as discharge was not recorded at LSD during an event of this magnitude, extrapolating the rating curve may create inaccuracies.

The post intervention LSD stage curve is calculated to intercept the pre LSD curve at 0.486m. This suggests that any event, which caused the Springfield Dumble to exceed this stage would overwhelm the interventions. Similarly, two post intervention points (2nd and 10th April 2018) were observed to be closer to the pre intervention relationship within Figure 5.41. This may be due to decreasing impact of the NFM interventions as event magnitude increases.

On the 10th of April 2018, a peak discharge of 45.6ls^{-1} was recorded at the USD logger. This is comparable to the 21st of November 2016 event, when a peak discharge 46.6 ls^{-1} was recorded. Peak discharge for the 2016 pre intervention event at LSD was recorded at 458.54 ls^{-1} whilst during the 2018 post intervention event a peak discharge of 346.9 ls^{-1} was recorded at the LSD logger. Therefore, for a comparable event, peak discharge at the LSD logger was lower post NFM intervention.

Further evidence to suggest change can be seen when assessing the 30th of December 2017 event highlighted in Figure 5.41. This event was a shorter duration event with a higher magnitude 60 minute rainfall when compared to other events. During this event, overland flow was significant, with the bunds storing a large percentage of runoff during the peak discharge of the event. As shown within Figure 5.41, the 30/12/17 event point sits below the pre NFM intervention trendline, with LSD peak discharge lower than would have been expected. Again, this provides evidence that NFM has had a positive impact on the hydrograph and reduced peak flows for this event.

Despite this, there was no significant differences found through statistical testing to suggest a wider reduction of peak discharge values. Hydrograph parameters between USD and LSD, such as time to peak, time to recede and event duration were tested for pre and post intervention changes, but findings were not significant at $p=0.05$ (Table 5.11). NFM intervention was found to have no statistically significant impacts on peak stage, peak discharge, time to peak, lag time, time to recede and event duration on the Springfield Dumble (Table 5.11).

No significant change was found in the celerity of the peak (flood wave), nor in the lag time between the USD and LSD peak (Table 5.11).

For the Parklane Dumble, this could not be tested due to insufficient data because of the Upper Parklane Dumble logger failing (Table 5.2).

Time to peak and time to recede within the Potwell Dyke hydrographs were found to have a significant difference post-NFM, with mean time to peak and time to recede found to be longer post NFM when compared to pre-NFM hydrographs (Table 5.11).

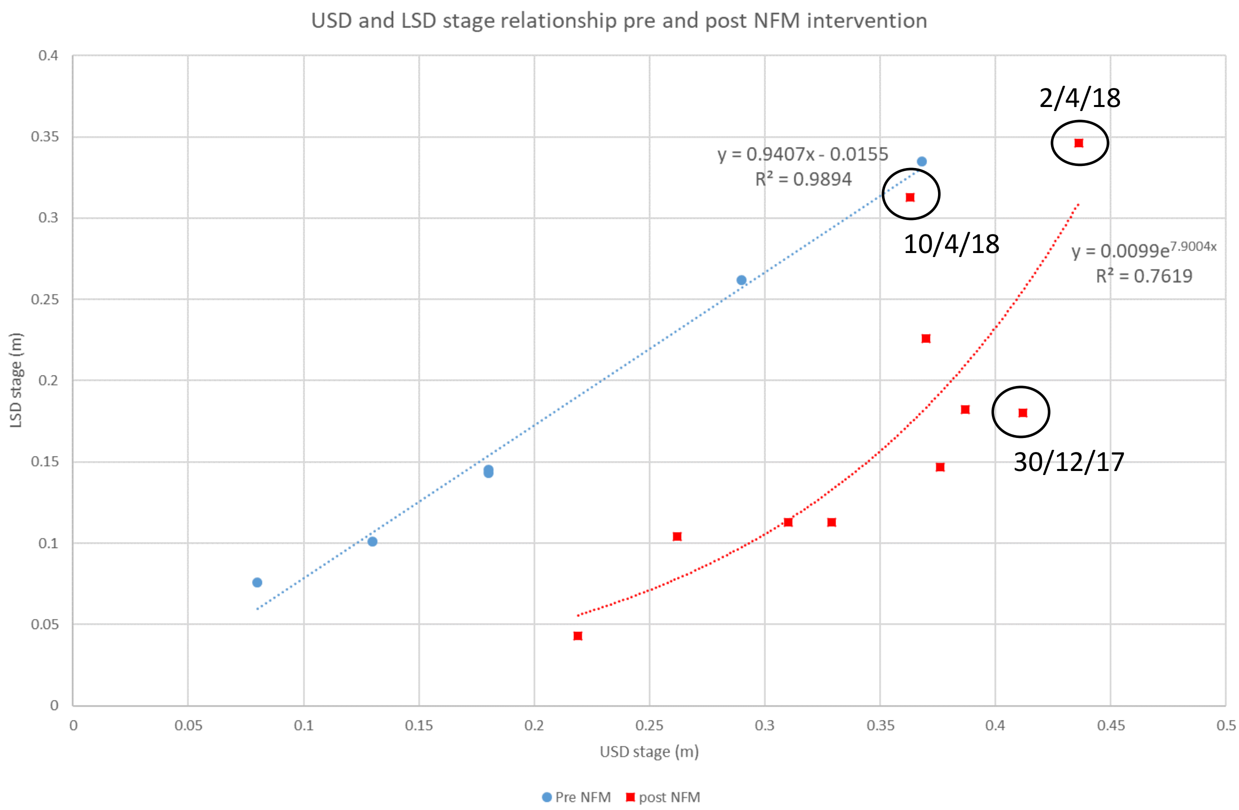

Figure 5.41 USD and LSD stage relationship pre and post NFM intervention. Pre intervention R2 = 0.9894, post intervention R2 = 0.7619.

*Table 5.11 Statistical test results using Pre and Post NFM hydrograph parameter data. *significance at P= 0.05 , **significance at P= 0.01*

	Hypothesis	Normally distributed	Test used	Mann Whitney U	z	p	t	N pre	N post	Significant at P 0.05
Springfield Dumble	Mean LSD peak stage has changed after NFM		T test			0.206	-1.296	12	16	ns
	Mean LSD Peak Q has changed after NFM		T test			0.121	-1.603	12	16	ns
	Mean LSD lag time has changed after NFM		T test			0.191	1.344	12	15	ns
	Mean LSD time to peak has changed after NFM		T test			0.785	-0.275	12	15	ns
	Mean LSD time to recede has changed after NFM	*	Mann Whitney U	74	-0.781	0.456		12	15	ns
	Mean LSD total event duration has changed post NFM	*	Mann Whitney U	74.5	-0.489	0.631		12	14	ns
Parklane Dumble	Mean LPD peak stage has changed after NFM	*	Mann Whitney U	81.5	-0.673	0.501		12	16	ns
	Mean LPD Peak Q has changed post NFM		T test			0.763	-0.304	12	16	ns
	Mean LPD lag time has changed after NFM		T test			0.097	1.727	12	15	ns
	Mean LPD time to peak has changed after NFM	*	Mann Whitney U	73	-0.83	0.407		12	15	ns
	Mean LPD time to recede has changed after NFM	*	Mann Whitney U	74	-0.781	0.435		12	15	ns
	Mean LPD total event duration has changed after NFM	*	Mann Whitney U	67.5	-0.849	0.396		12	14	ns
Potwell Dyke	Mean PD peak stage has changed after NFM	*	Mann Whitney U	63	-1.532	0.125		12	16	ns
	Mean PD Peak Q has changed post NFM		T test			0.166	-1.426	12	16	ns
	Mean PD lag time has changed after NFM		T test			0.441	0.783	12	15	ns
	Mean PD time to peak has changed after NFM	*	Mann Whitney U	25.5	-3.01	0.003		12	14	y**
	Mean PD time to recede has changed after NFM	*	Mann Whitney U	45.5	-1.981	0.048		12	14	y*
	Mean PD total event duration has changed after NFM	*	Mann Whitney U	35	-1.908	0.056		12	11	ns
	Springfield Dumble celerity has changed after NFM		T test			0.145	-1.046	7	15	ns
	Parklane Dumble celerity has changed after NFM	-	-	-	-	-	-	-	-	-
	The time lag between USD and LSD peak stage has changed after NFM	*	Mann Whitney U	42	-0.741	0.459		7	15	ns
	The time lag between UPD and LPD peak stage has changed after NFM	-	-	-	-	-	-	-	-	-

5.3.3 The impact of temporary water storage in bunds on stream discharge

Bunds were shown to fill during several rainfall events. Example bund stage graphs from two of the gauged bunds are shown in Figure 5.42 and 5.43.

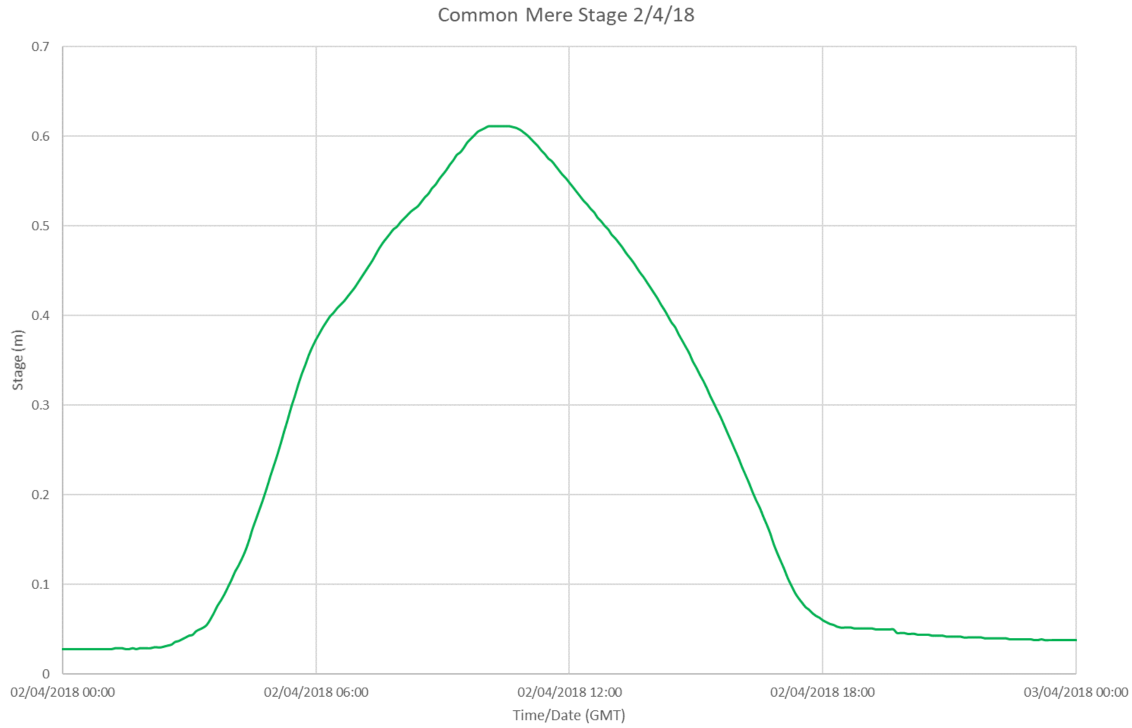

Figure 5.42 Common Mere bund stage 2/4/18.

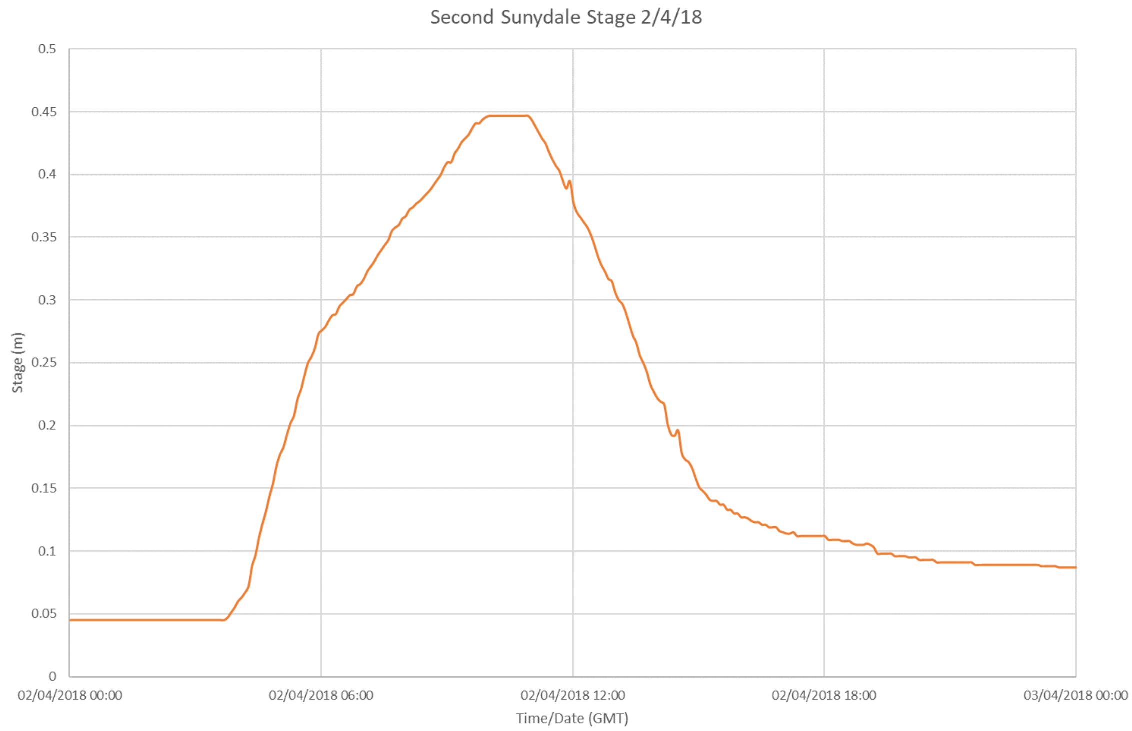

Figure 5.43 Second Sunnydale bund stage 2/4/18.

Results are presented showing the impact of water storage within the bunds on stream discharge (Table 5.12). The Common Mere bund has been found to have the highest average maximum storage from sampled events, with a mean value of 9.6 ls^{-1} and a range between 0 - 46.7ls^{-1}. The 2nd Sunnydale and Parklane bunds have a mean maximum storage of 3.3 ls^{-1} and 1.3 ls^{-1} respectively.

Table 5.12 Bund max stage and storage data

Event date	Common Mere max water level (m)	2nd Sunnydale max Water Level (m)	Parklane max Water Level (m)	Common Mere max storage (ls^{-1})	2nd Sunnydale max storage (ls^{-1})	Parklane max storage (ls^{-1})
30/12/2017	0.484	0.253	0.308	28.0	5.5	2.1
05/01/2018	0.138	0.138	0.273	2.8	1.8	1.2
24/01/2018	0.241	0.141	0.271	0.0	0.0	0.9
09/02/2018	0.103	0.085	0.098	0.9	0.0	0.4
14/02/2018	0.099	0.088	0.128	0.7	0.7	0.6
09/03/2018	-	0.101	1.186	-	1.2	1.1
10/03/2018	0.023	0.101	0.17	0.0	1.2	0.2
12/03/2018	0.024	1.81	0.321	0.0	6.0	1.8
30/03/2018	0.302	0.204	0.241	11.1	3.1	1.9
02/04/2018	0.611	0.447	0.408	24.8	8.4	2.8
04/04/2018	0.199	0.147	0.314	7.2	2.1	0.3
10/04/2018	0.65	0.472	0.404	46.7	14.9	4.0
13/04/2018	0.25	0.15	0.292	6.7	1.6	0.0
02/05/2018	0.162	-	0.118	2.5	-	0.6
27/12/2018	0.238	0.071	0.195	3.67	0.29	0.9

Reductions in peak discharge as a result of the single bund in the Parklane Dumble subcatchment are shown in Table 5.13. The mean peak discharge reduction is 0.6 ls^{-1} with a range of 0 – 3.5ls^{-1}.

Within the Springfield Dumble subcatchment, four bunds were constructed but only two of these had stage logging equipment installed. The catchment ratio method was used to predict the storage of ungauged bunds, as described in section 5.2.3.3. Data from each gauged bund were used to estimate the storage of ungauged bunds. This means that two values of peak discharge reduction were obtained (Tables 5.14 and 5.15).

Observed and predicted Common Mere bund storage and discharge is shown in Figure 5.44. Common Mere bund predicted storage was calculated using the catchment ratio method set out within the methodology. 2nd Sunnydale observed data was used to calculate the predicted storage. The chart gives some indication of validation, with the pattern of the predicted storage following that of the observed. However, the bund predicted discharge, calculated using the equations explained in the methodology, does not fit with the observed data. Results from the rainfall-runoff method to predict ungauged bunds proved to be unreliable. Results for this method are presented within Appendix C.

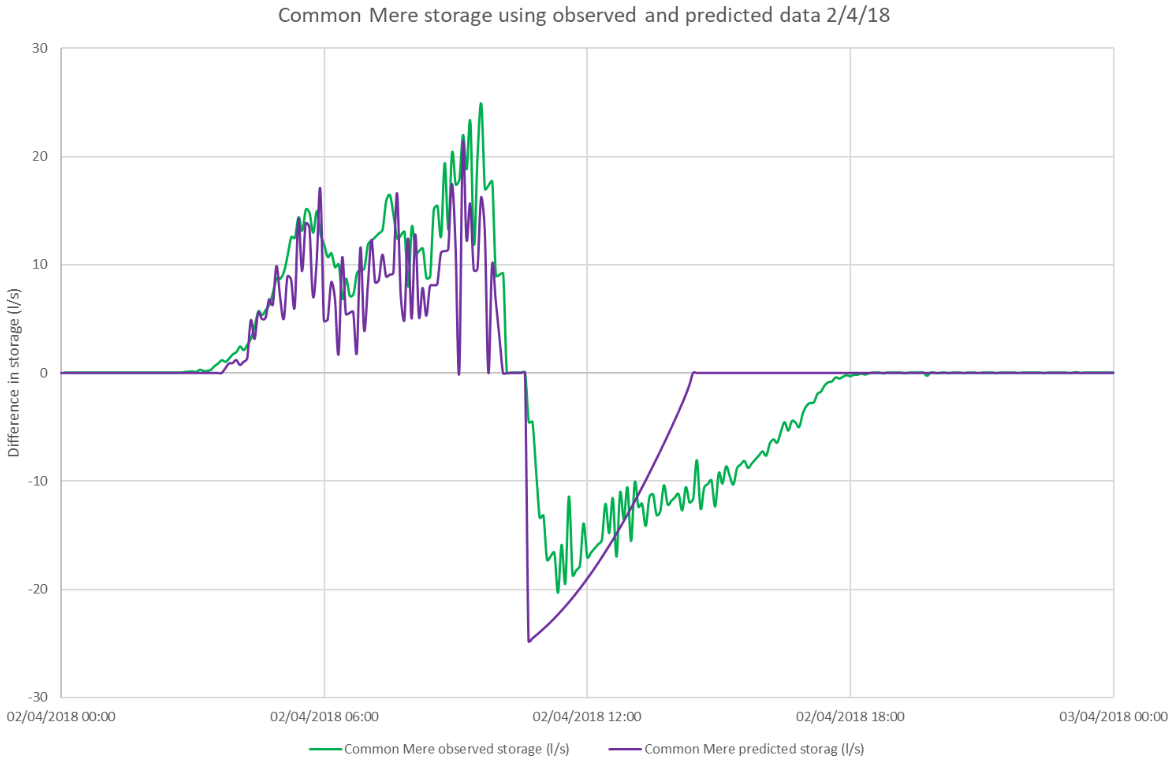

Figure 5.44 Common Mere bund storage using observed and predicted data 2/4/18.

Results showing peak discharge reduction at the LSD logger, using the catchment ratio method, are presented in Table 5.14. A mean reduction in peak discharge of 9.8 ls^{-1} is calculated using data obtained from the Common Mere bund, with reductions ranging between -7.8 – 59.7 ls^{-1}. When using data from the 2nd Sunnydale bund to predict ungagged bund storage, a mean reduction in peak discharge of 8.7 ls^{-1} is calculated, with reductions ranging between -2.4 – 51.1 ls^{-1}.

Reductions in peak discharge on the Potwell Dyke at Park Lodge, calculated using the catchment ratio method, are shown in Table 5.15. Using data from the Common Mere bund, a mean reduction in peak discharge of 5.8 ls^{-1} is calculated with reductions ranging from -2.3 – 42.6 ls^{-1}. When using data from the 2nd Sunnydale bund, a mean reduction in peak discharge of 4.8 ls^{-1} is calculated, with reductions ranging between -0.9 – 35.7 ls^{-1}. More detail of impacts on individual events is given in sections 5.3.3.1 – 5.3.3.4.

Table 5.13 Calculated reductions in Parklane Dumble discharge.

Event date	Observed LPD peak Q (l/s)	Simulated LPD peak Q (l/s)	LPD peak Q reduction (l/s)	LPD peak Q reduction %	Time delay to peak Q (mins)
30/12/2017	157.3	158.1	0.8	0.5	0
05/01/2018	27.9	28.2	0.3	1.1	0
24/01/2018	21.4	21.4	0	0.0	0
09/02/2018	2.3	2.5	0.2	8.0	0
14/02/2018	2.3	2.5	0.2	8.0	0
09/03/2018	No significant rise in Q				
10/03/2018	12.2	12.4	0.2	1.6	0
12/03/2018	67.2	66.5	-0.7	-1.1	0
30/03/2018	1.1	1.6	0.5	31.3	20
02/04/2018	63.3	65.2	1.9	2.9	0
04/04/2018	No significant rise in Q				
10/04/2018	18	21.5	3.5	16.3	0
13/04/2018	No significant rise in Q				
02/05/2018	1.5	1.6	0.1	6.3	0
27/12/2018	77.8	78.2	0.4	0.5	0

Table 5.14 Calculated reductions in Springfield Dumble discharge using the catchment ratio method.

	Common Mere bund data used as predictor					2nd Sunnydale bund data used as predictor				
Event date	Observed LSD peak Q (l/s)	Simulated LSD peak Q (l/s)	LSD peak Q reduction (l/s)	LSD peak Q reduction %	Time delay to peak Q (mins)	Observed LSD peak Q (l/s)	Simulated LSD peak Q (l/s)	LSD peak Q reduction (l/s)	LSD peak Q reduction %	Time delay to peak Q (mins)
30/12/2017	63.0	101.9	38.9	38.2	0	63.0	93.3	30.3	32.5	0
05/01/2018	44.3	41.9	-2.4	-5.7	25	44.3	41.92	-2.4	-5.7	25
24/01/2018	20.3	20.3	0.0	0.0	0	20.3	20.3	0.0	0.0	0
09/02/2018	9.2	10.2	1.0	9.8	20	9.2	10.6	1.4	13.2	30
14/02/2018	7.8	7.8	0.0	0.0	0	7.8	7.8	0.0	0.0	0
09/03/2018	Data missing due to logger failure					18.8	18.8	0.0	0.0	0
10/03/2018	18.8	18.8	0.0	0.0	0	18.8	18.8	0.0	0.0	0
12/03/2018	29.6	29.6	0.0	0.0	0	29.6	29.6	0.0	0.0	0
30/03/2018	112.4	104.6	-7.8	-7.5	15	112.4	113.2	0.8	0.7	0
31/03/2018	181.4	192.0	10.6	5.5	25	181.4	190.85	9.4	5.0	25
02/04/2018	509.3	543.8	34.5	6.3	0	509.3	540.5	31.2	5.8	0
04/04/2018	27.1	29.7	2.6	8.8	40	27.1	27.7	0.6	2.2	25
10/04/2018	336.1	395.8	59.7	15.1	-5	336.1	387.2	51.1	13.2	-5
13/04/2018	27.1	34.1	7.0	20.5	40	27.1	32.6	5.5	16.9	25
02/05/2018	17.9	17.9	0.0	0.0	30	Data missing due to logger failure				
27/12/2018	40.0	42.5	2.5	5.9	0	40.0	41.9	1.9	4.5	0

Table 5.15 Calculated reductions in Potwell Dyke (Park Lodge) discharge using the catchment ratio method.

	Common Mere bund data used as predictor					2nd Sunnydale bund data used as predictor				
Event date	Observed PD peak Q (l/s)	Simulated PD peak Q (l/s)	PD peak Q reduction (l/s)	PD peak Q reduction %	Time delay to peak Q (mins)	Observed PD peak Q (l/s)	Simulated PD peak Q (l/s)	PD peak Q reduction (l/s)	PD peak Q reduction %	Time delay to peak Q (mins)
30/12/2017	938.4	956.2	17.8	1.9	0	938.4	955.1	16.7	1.7	0
05/01/2018	417.0	417.3	0.3	0.1	-10	417.0	417.1	0.1	0.0	-10
24/01/2018	300.7	300.7	0.0	0.0	0	300.7	300.7	0	0.0	0
09/02/2018	114.9	114.8	-0.1	-0.1	0	114.9	114.8	-0.1	-0.1	0
14/02/2018	91.0	91	0.0	0.0	0	91.0	91.0	0	0.0	0
09/03/2018	Data missing due to logger failure					427.2	427.2	0	0.0	0
10/03/2018	427.2	427.2	0.0	0.0	0	427.2	427.2	0	0.0	0
12/03/2018	1047.9	1047.3	-0.6	-0.1	0	1047.9	1047.3	-0.6	-0.1	0
30/03/2018	558.0	559.2	1.2	0.2	0	558.0	559.2	1.2	0.2	0
31/03/2018	669.4	674.3	4.9	0.7	0	669.4	673.8	4.4	0.7	0
02/04/2018	2160.9	2203.5	42.6	1.9	0	2160.9	2196.6	35.7	1.6	0
04/04/2018	349.1	349.8	0.7	0.2	0	349.1	349.8	0.7	0.2	0
10/04/2018	2160.9	2176.5	15.6	0.7	20	2160.9	2176.0	15.1	0.7	0
13/04/2018	409.0	406.7	-2.3	-0.6	0	409.0	408.1	-0.9	-0.2	0
02/05/2018	188.4	189.1	0.7	0.4	0	Data missing due to logger failure				
27/12/2018	497.1	497.3	0.2	0.04	0	497.1	497.3	0.2	0.0	0

5.3.3.1 30th December 2017

During the event of 30th December 2017, an observed peak discharge of 63.0 ls^{-1} was recorded at the LSD logger. Figure 5.45 shows reductions in peak discharge as a result of bunding, using data from the 2nd Sunnydale bund to estimate the impact of the two ungagged bunds. For this event a simulated peak of 93.3 -101.9 ls^{-1} is calculated (Table 5.14). This results in a simulated peak discharge reduction of 32.5 – 38.2%, meaning discharge would have been higher if the bund was not in place. The simulated discharge hydrograph in Figure 5.45 shows a change in hydrograph shape, with discharge shifting from the rising limb and peak onto the falling limb.

Figure 5.46 shows reductions in peak discharge at the LPD logger as a result of the single Parklane bund. An observed peak of 157.3 ls^{-1} was recorded with a simulated peak of 158.1 ls^{-1} calculated, representing a 0.5% reduction in peak discharge from the single bund in this catchment.

During this event at the PD logger, an observed peak of 938.4 ls^{-1} was recorded and a simulated peak of 955.1-956.2 ls^{-1} calculated (Figure 5.47). A reduction in peak discharge of 1.7-1.9% was calculated. However as shown in Figure 5.49, just before peak discharge occurs, reductions in discharge as a result of bunding are at their greatest.

During this event, the Common Mere bund stored more discharge than other bunds, with a maximum of 28.0ls^{-1} (Figure 5.48). Micklebarrow Springfield, 2nd Sunnydale and 1st Sunnydale bunds created a maximum storage of 6.3, 5.5 and 0.01 ls^{-1}. As shown in Figure 5.49, the Common Mere bund maximum storage occurs 23 minutes before LSD peak discharge. However, the Figure also shows that the bunds were effective in storing water during the stream peak discharge and so had a positive impact which reduced peak discharge during this event.

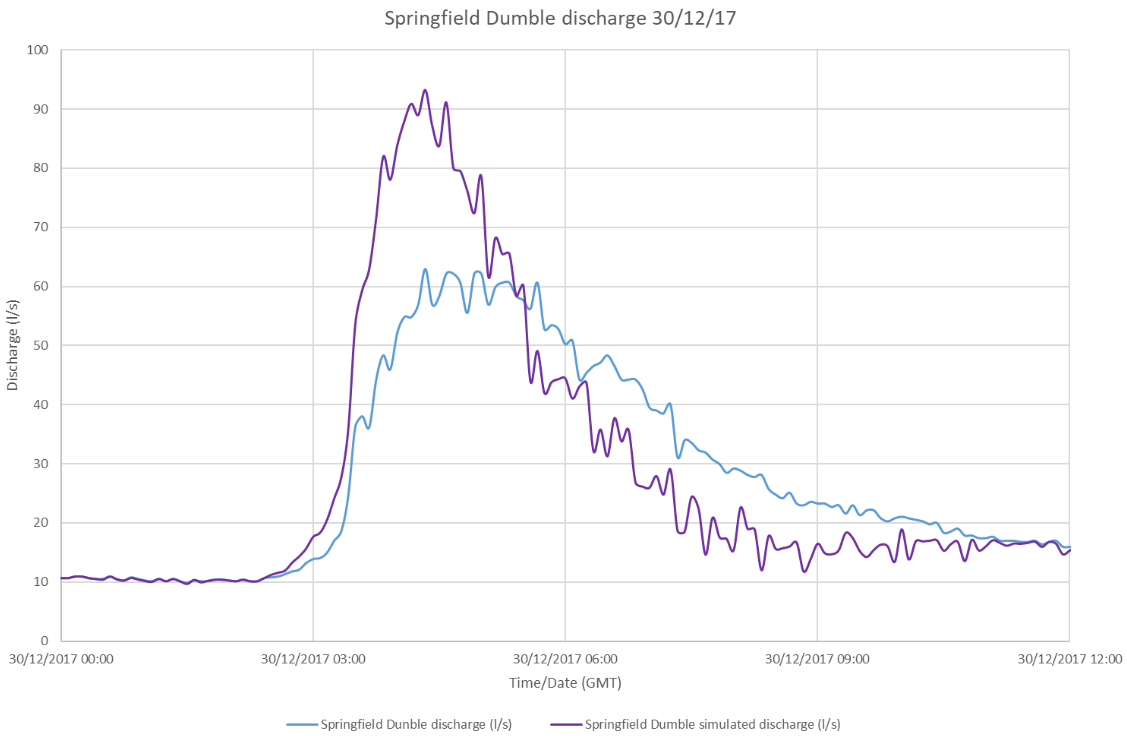

Figure 5.45 Observed and simulated Springfield Dumble discharge 30/12/17 using 2nd Sunnydale bund data.

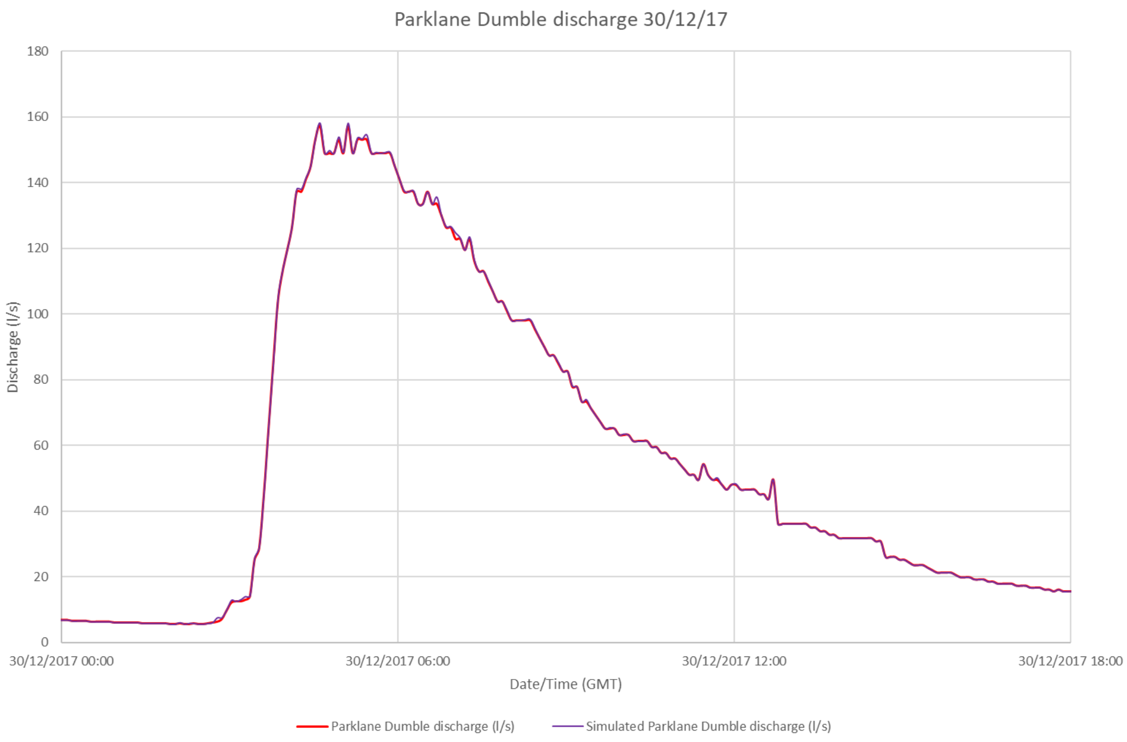

Figure 5.46 Observed and simulated Parklane Dumble discharge 30/12/17.

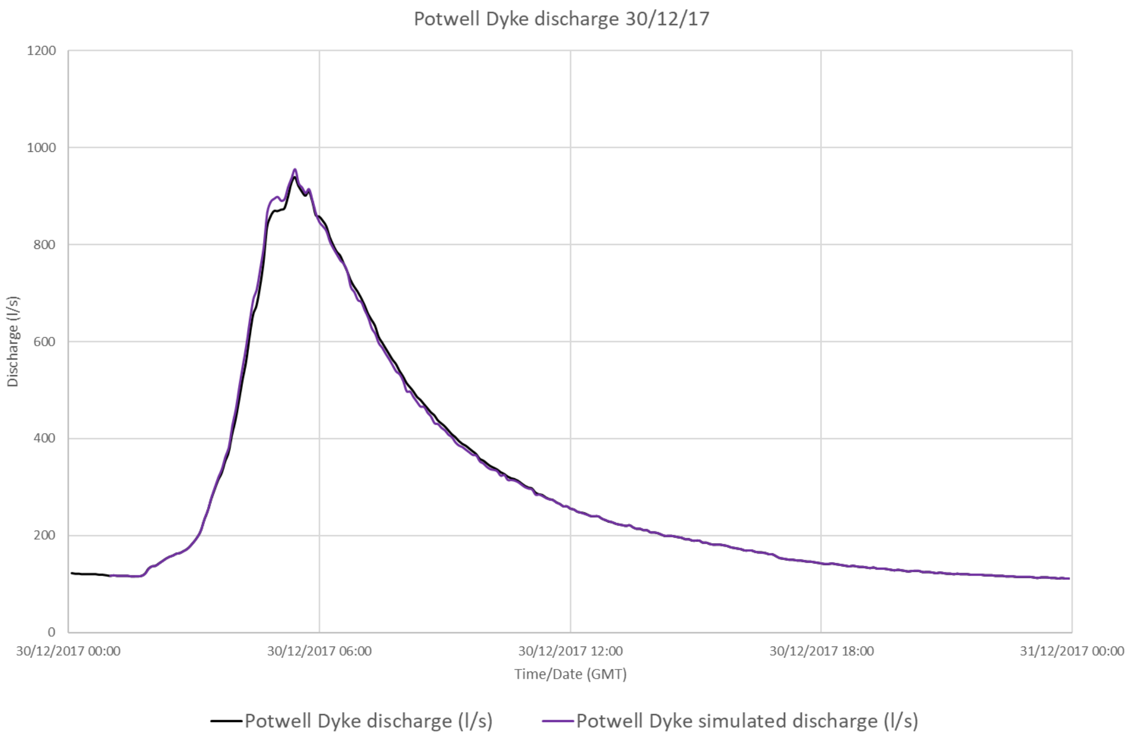

Figure 5.47 Observed and simulated Potwell Dyke discharge 30/12/17 using 2nd Sunnydale bund data.

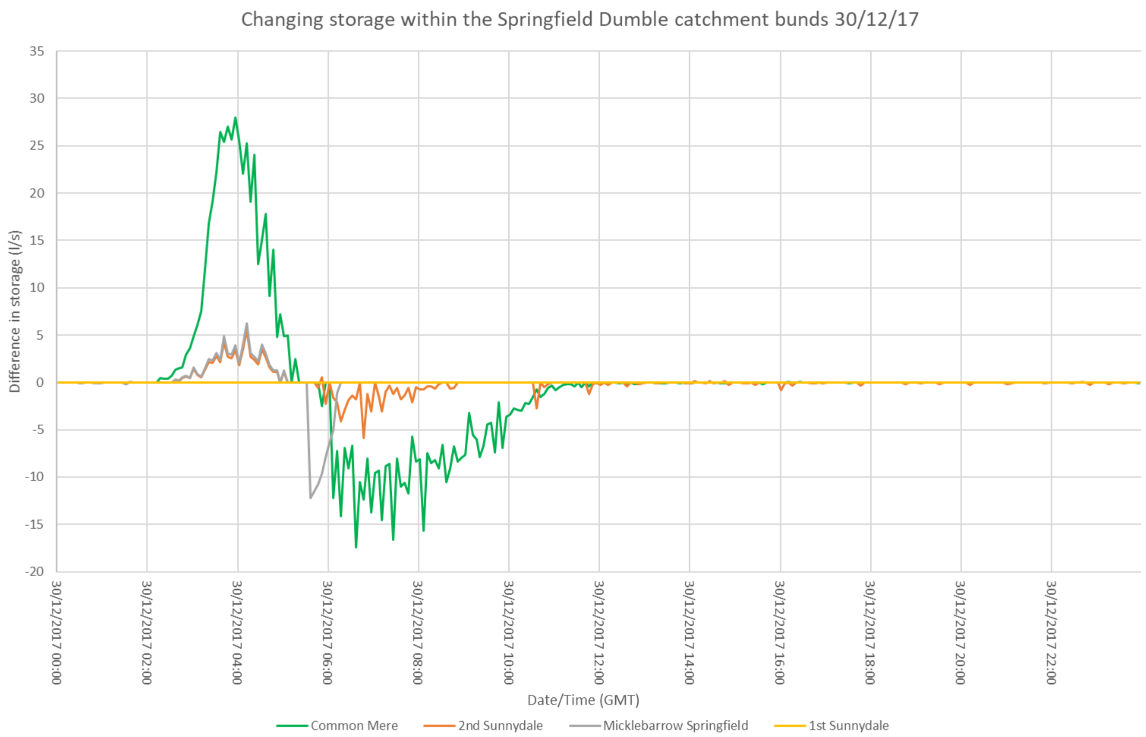

Figure 5.48 Changing storage, including predicted bunds, within the Springfield Dumble catchment bunds 30/12/17.

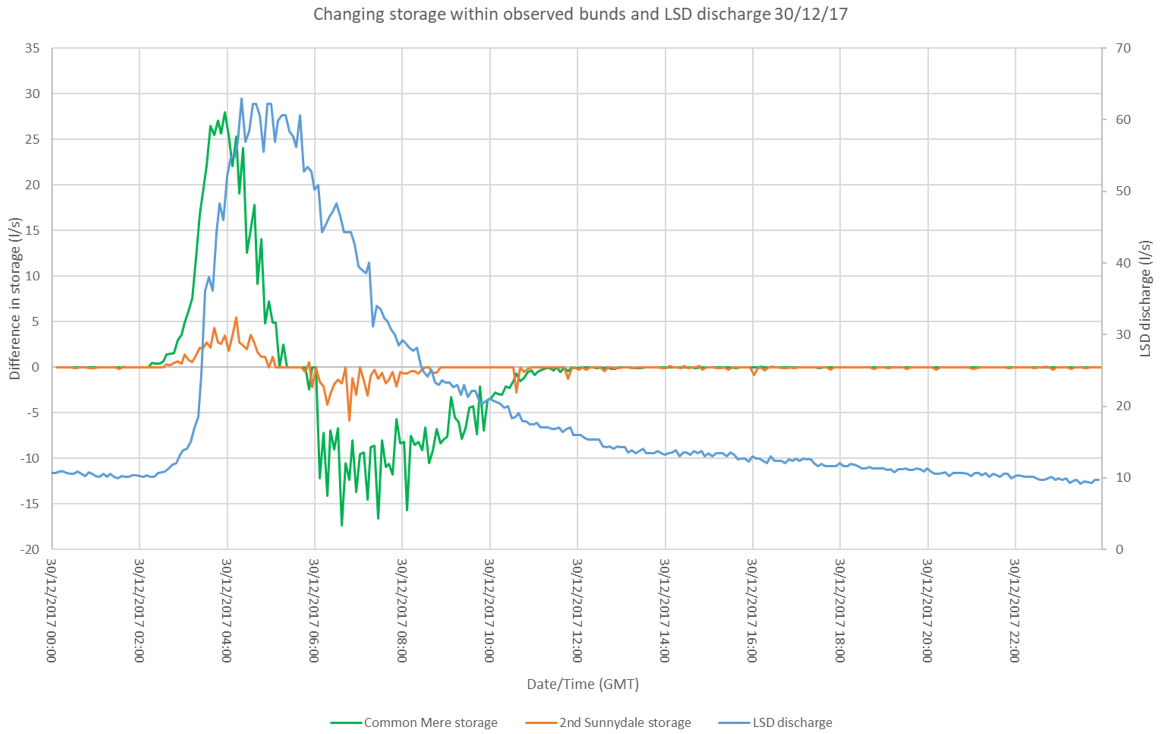

Figure 5.49 Changing storage within observed bunds and LSD discharge 30/12/17.

5.3.3.2 2nd April 2018

An observed peak of 509.3 ls^{-1} was recorded at the LSD logger during the 2nd April 2018 event. As shown in Figure 5.50, a simulated peak discharge of 540.5 -543.8 ls^{-1} was calculated resulting in a reduction in peak discharge of 6.3- 5.8% (Table 5.14). Again, discharge is shown to shift from the rising limb and peak to the falling limb. However, the reduction in peak discharge as a percentage is less during this event.

At LPD, an observed peak of 63.2 ls^{-1} was recorded with a simulated peak of 65.2 ls^{-1} calculated, resulting in a peak discharge reduction of 2.9% (Figure 5.51).

For the Potwell Dyke at Park Lodge, an observed peak of 2160.9 ls^{-1} was recorded, compared to a simulated peak of 2196.6 – 2176.5 ls^{-1} (Figure 5.52). A reduction in peak discharge of 1.6-1.9% is calculated which, when compared to reductions at the subcatchment scale, is somewhat limited.

As shown in Figure 5.53, the Common Mere bund stored more discharge than other bunds, with a maximum storage of 24.8 ls^{-1}. Using the 2nd Sunnydale bund data, Micklebarrow Springfield, Common Mere and 1st Sunnydale had a maximum storage of 9.6, 8.4 and 0.01ls^{-1} respectively. From Figure 5.54, both gauged bunds are shown to have stored water during LSD peak discharge and so functioned as designed.

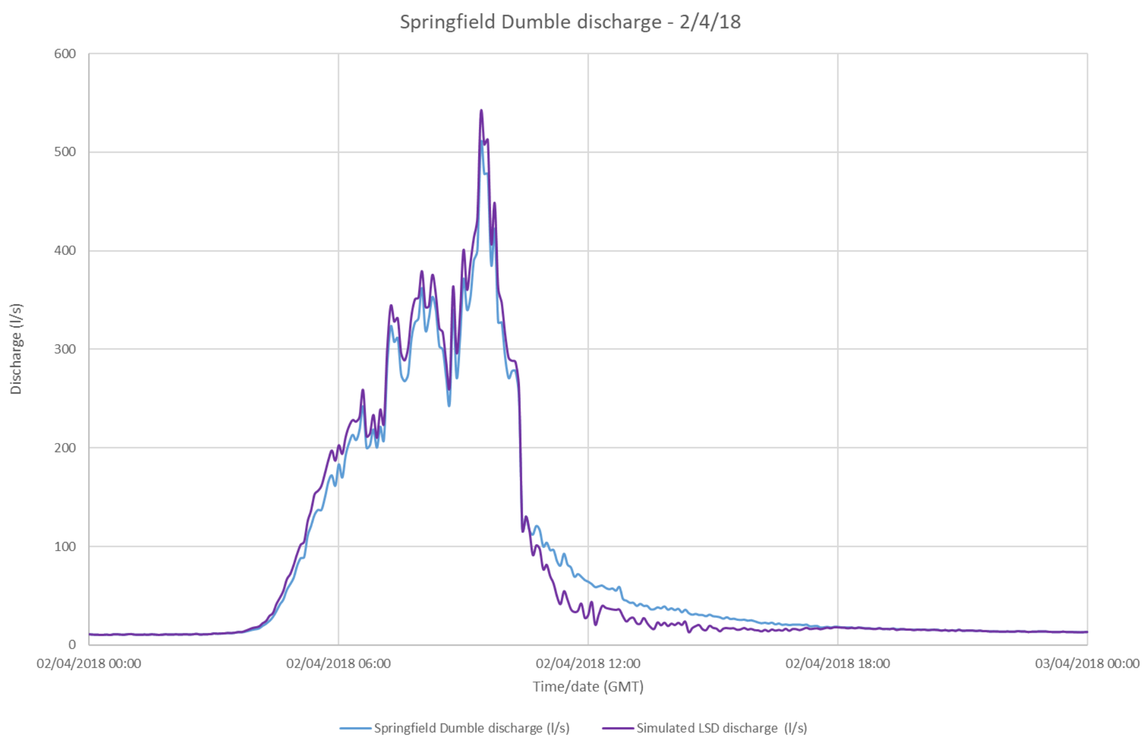

Figure 5.50 Observed and simulated Springfield Dumble discharge 2/4/18 using 2nd Sunnydale bund data.

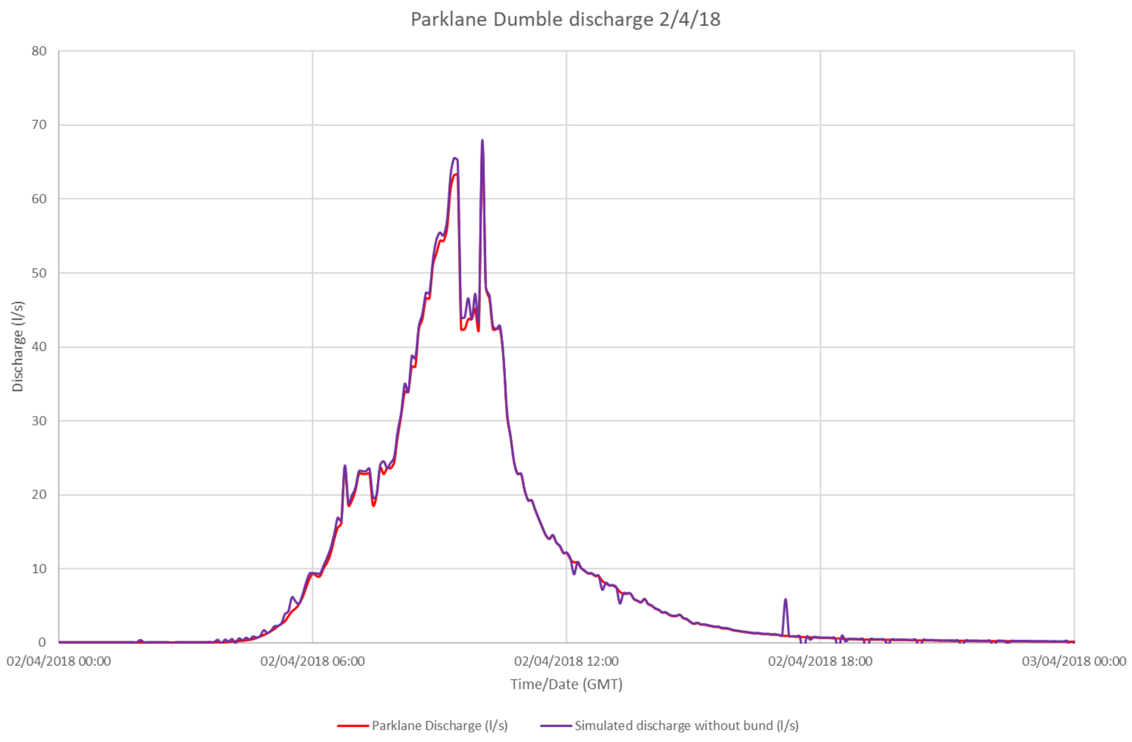

Figure 5.51 Observed and simulated Parklane Dumble discharge 2/4/18.

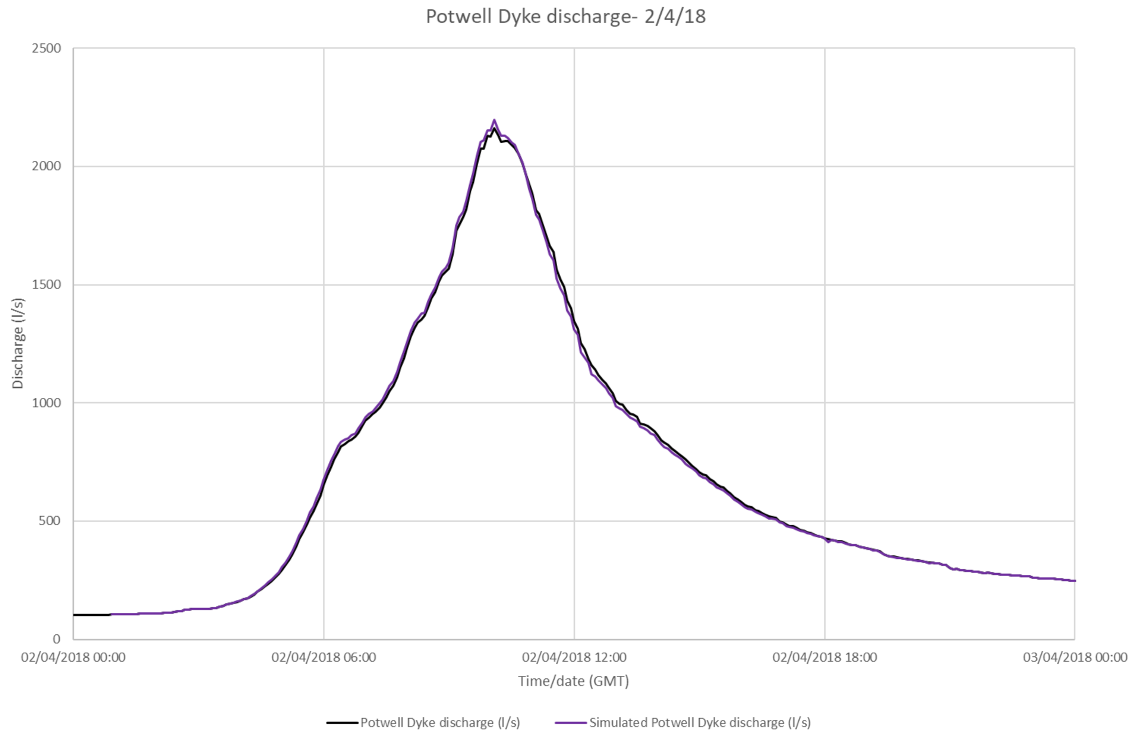

Figure 5.52 Observed and simulated Potwell Dyke discharge 2/4/18 using 2nd Sunnydale bund data.

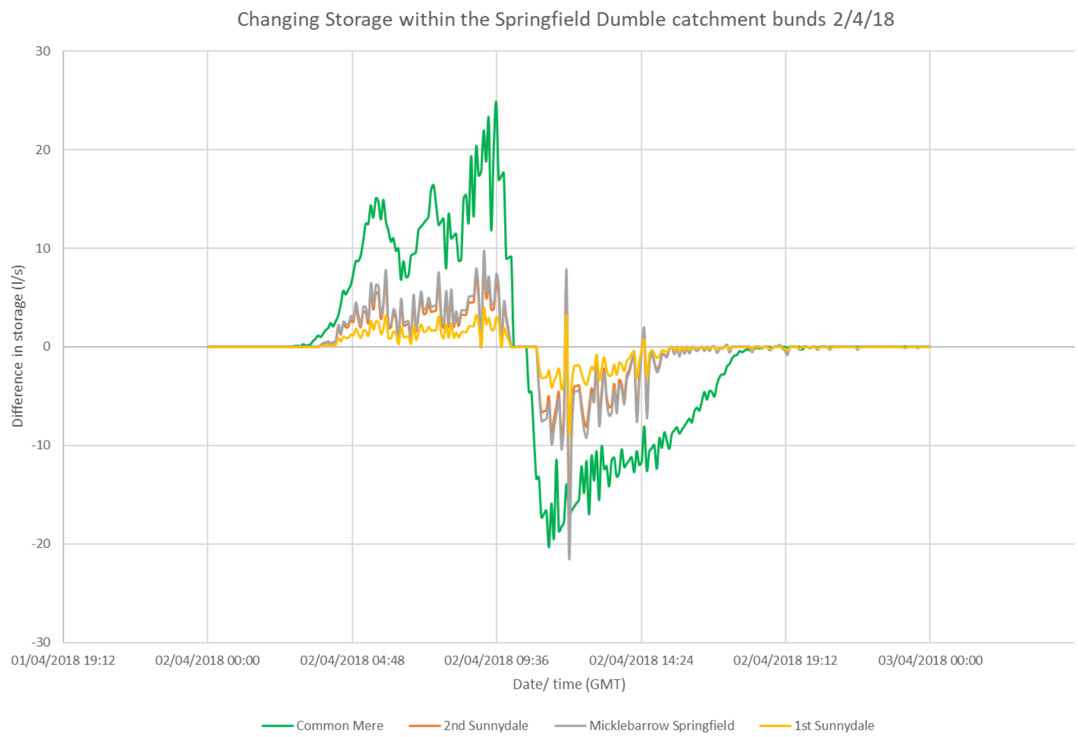

Figure 5.53 Changing storage within the Springfield Dumble catchment bunds 2/4/18.

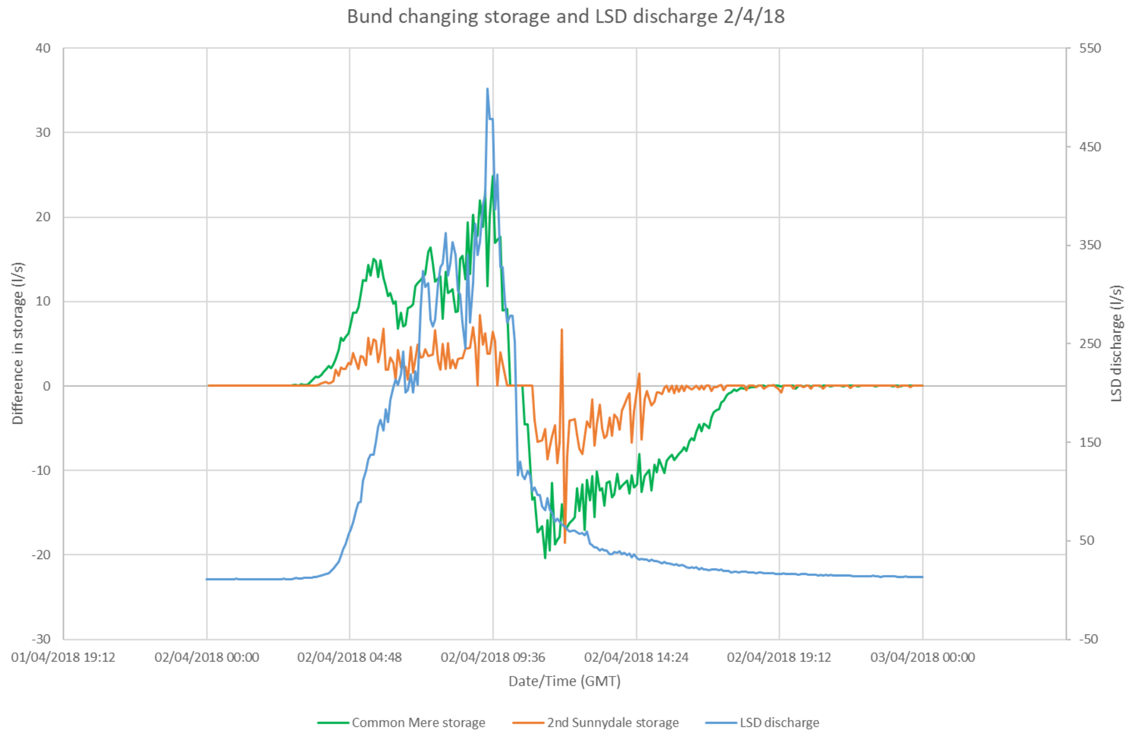

Figure 5.54 Changing storage within observed bunds and LSD discharge 2/4/18.

5.3.3.3 10th April 2018

During the 10th April 2018 event, an observed peak of 336.1 ls^{-1} was recorded at LSD, with a simulated peak of 387.2 – 395.8 ls^{-1} calculated (Table 5.14). This resulted in a reduction in peak discharge of 15.1- 13.2%. The hydrograph in Figure 5.55 shows a change in shape with discharge being moved from the rising limb and peak to the falling limb.

At the LPD logger, an observed peak of 18 ls^{-1} was recorded with a simulated peak of 21.5 ls^{-1} calculated (Figure 5.56). This resulted in a reduction in peak discharge of 16.3% from the single Parklane bund.

At the Potwell Dyke Park Lodge logger, an observed peak of 2160.9 ls^{-1} was recorded with a simulated peak of 2176.0 -2176.5 ls^{-1} calculated (Figure 5.57). This resulted in a reduction in peak discharge of 0.7% (Table 5.14). Figure 5.57 shows that maximum discharge reduction occurs before the peak of the Potwell Dyke hydrograph.

Figure 5.58 shows the changing storage within the Springfield Dumble catchment bunds. The Common Mere bund is found to store the greatest amount of water, with a maximum storage of 46.7 ls^{-1}. Micklebarrow Springfield, Common Mere and 1st Sunnydale bunds have a maximum storage of 16.9, 14.9 and 0.02 ls^{-1} respectively.

However, bund maximum storage values are not observed to be synchronised with LSD peak discharge in Figure 5.59. Common Mere and 2nd Sunnydale maximum storage occurs 45 minutes prior to LSD peak discharge. Although, the bunds are shown to be storing water during the peak of the LSD hydrograph and so are shown to be creating beneficial water storage during this event.

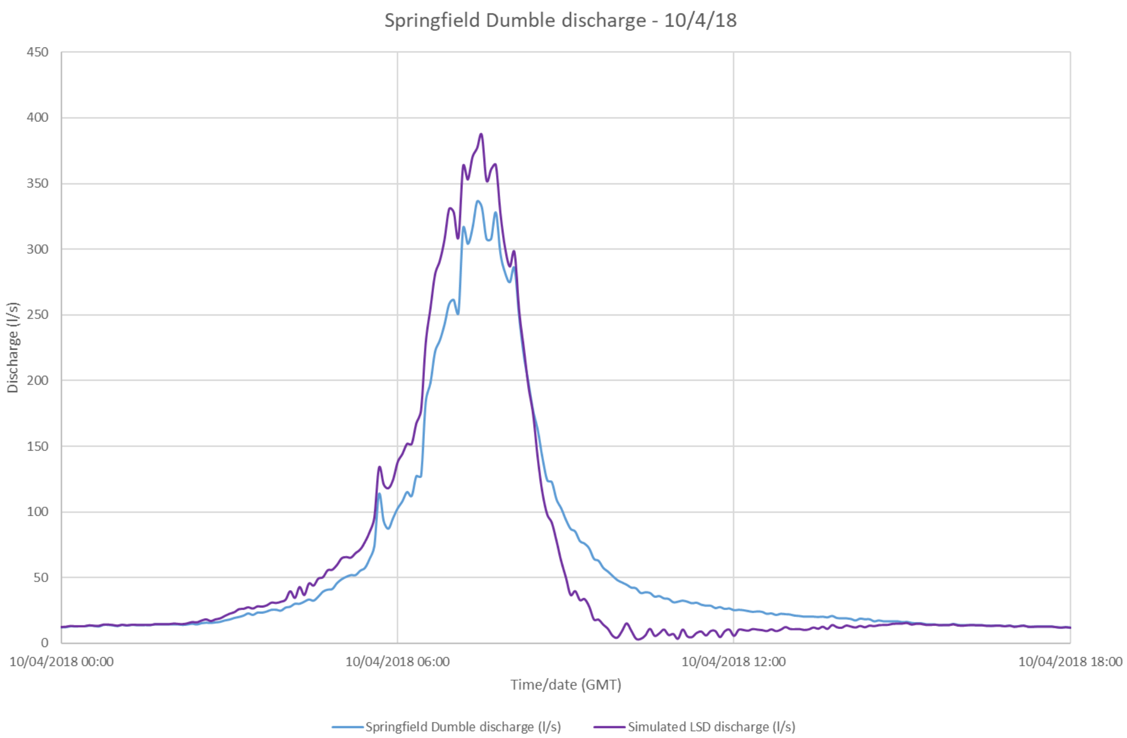

Figure 5.55 Observed and simulated Springfield Dumble discharge 10/4/18 using 2nd Sunnydale bund data.

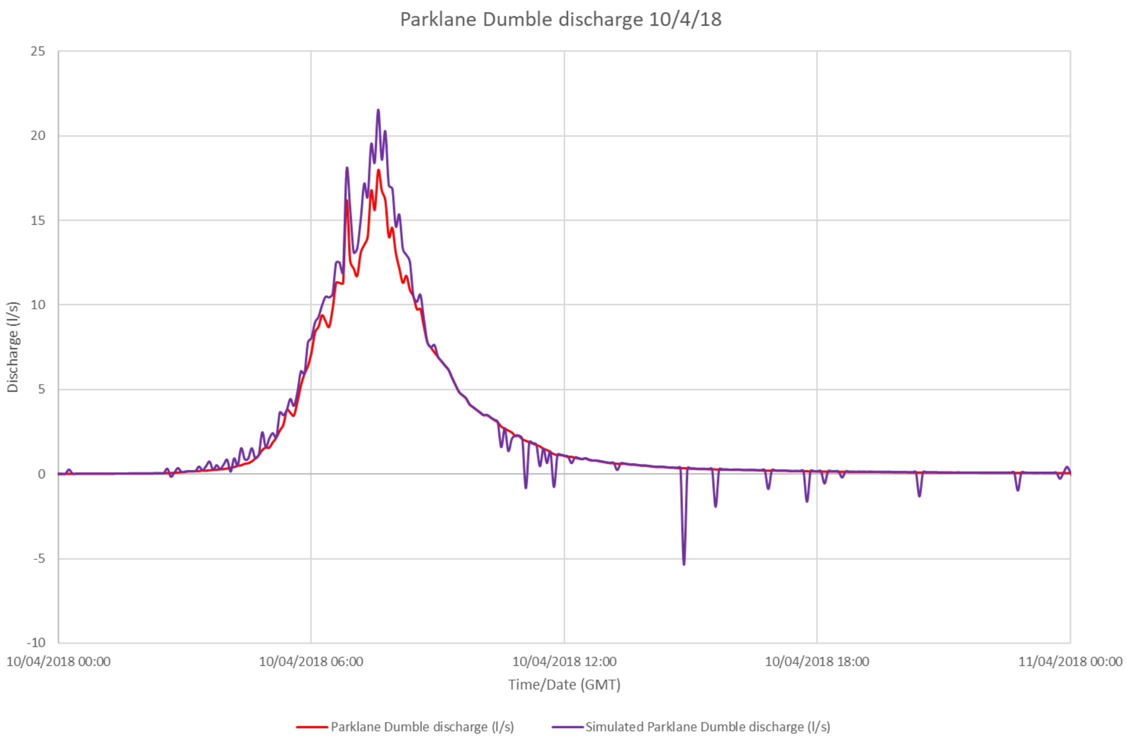

Figure 5.56 Observed and simulated Parklane Dumble discharge 10/4/18.

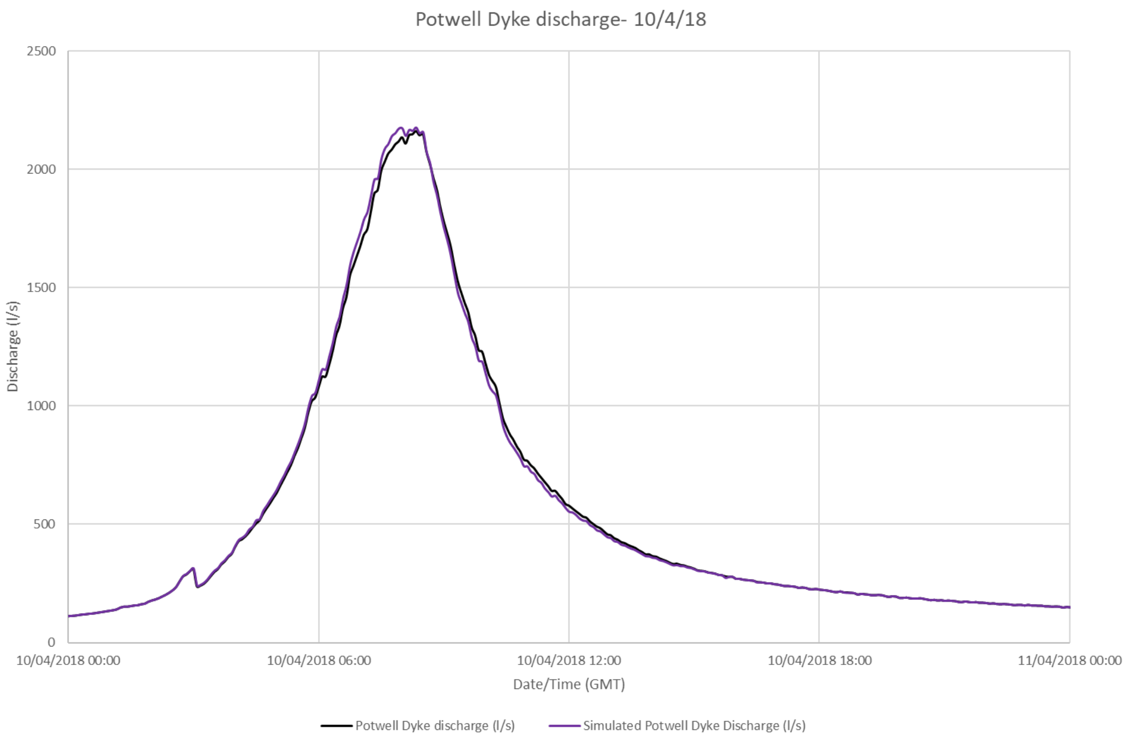

Figure 5.57 Observed and simulated Potwell Dyke discharge 10/4/18 using 2nd Sunnydale bund data.

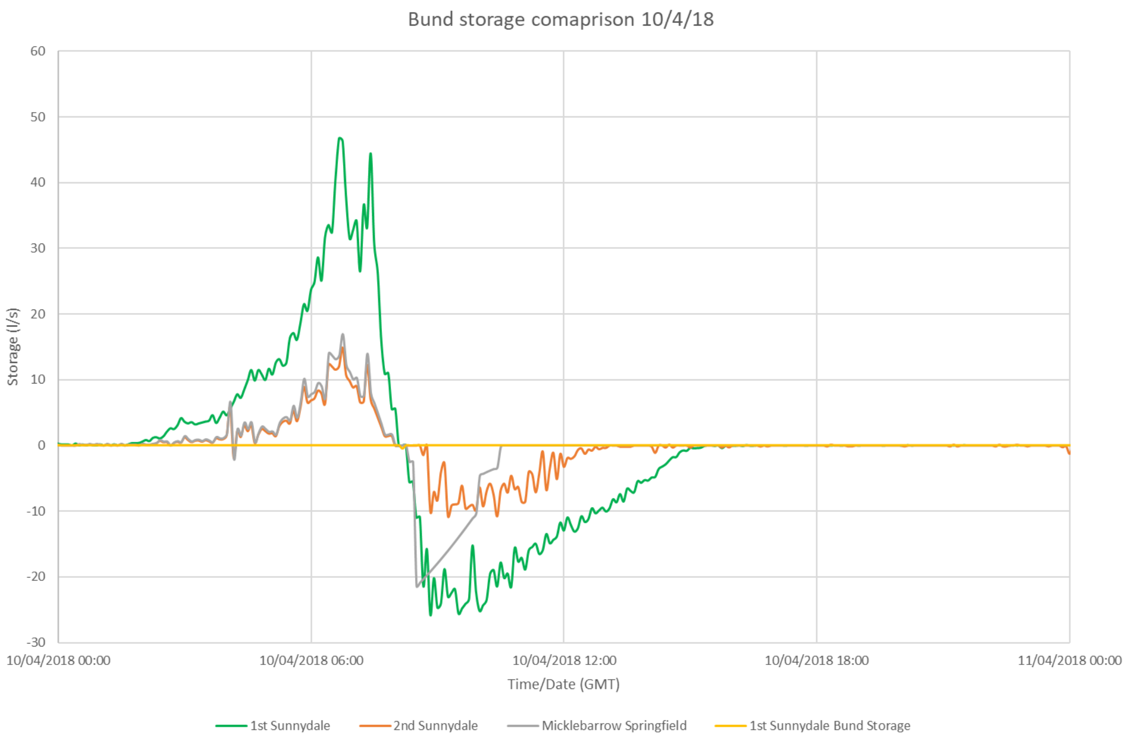

Figure 5.58 Changing storage within the Springfield Dumble catchment bunds 10/4/18.

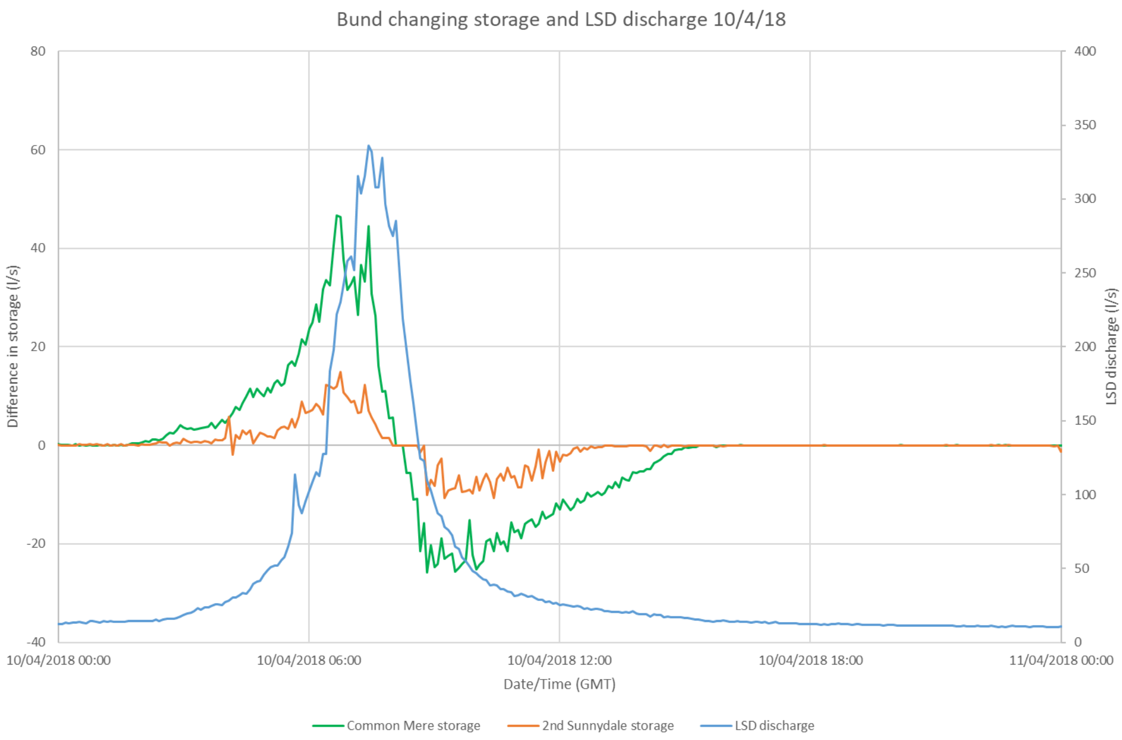

Figure 5.59 Changing storage within observed bunds and LSD discharge 10/4/18.

5.3.3.4 13th April 2018

During the 13th of April 2013 Event, the Springfield subcatchment bunds were observed to be discharging during Potwell Dyke peak discharge (Figure 5.60). As a result, peak discharge at the Potwell Dyke was increased by 0.9-2.3 ls^{-1} (0.6-0.9%). This event was a lower magnitude which did not cause flooding in Southwell. However, the results show that during some events, rainfall patterns may cause the bunds to negatively impact on peak discharge. These results are based on bund storage data only and do not take into account the impacts of LWD dams or the restoration which could have created positive storage and therefore reduced the hydrograph peak.

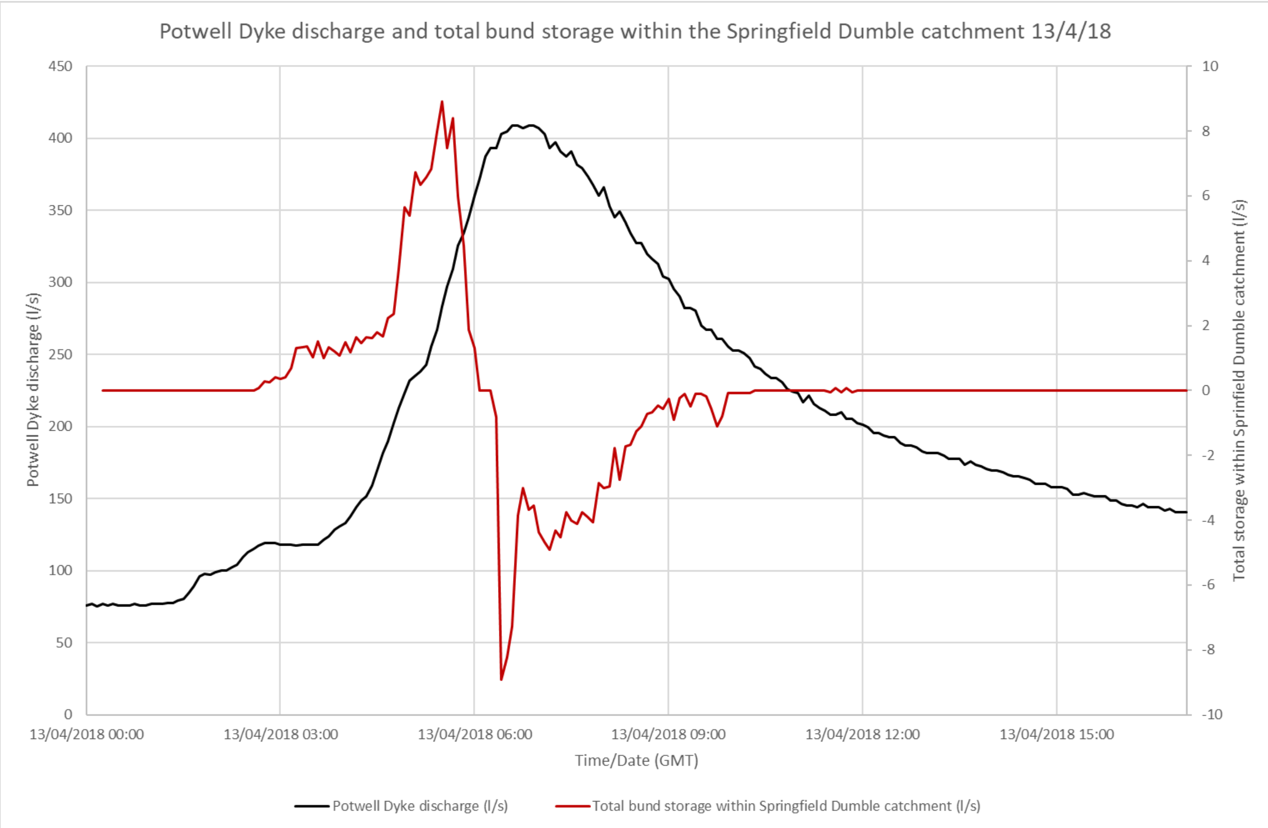

Figure 5.60 Potwell Dyke discharge and total bund storage within the Springfield Dumble catchment 13/4/18.

5.3.3.5 The impact of catchment wide storage on the Potwell Dyke hydrograph

To assess the impact of catchment wide storage, a greater number of bunds within the Potwell Dyke catchment were simulated using data from the 2nd April 2018 event. Based on the findings of Quinn *et al.* (2013) that 19,250m^3 of storage is required within a 10km^2 catchment to have a significant impact on peak flows, 20 bunds were modelled within the catchment. This represents a combined storage of 12,660m^3 within a 6km^2 catchment. A simulated storage volume was calculated by multiplying the Common Mere storage values at each time step by 20. The simulated storage values were then totalled with the observed hydrograph at PD to give a simulated hydrograph. Figure 5.61 shows the simulated hydrograph for the 2nd April 2018 event, representing 20 bunds with optimum storage during PD peak discharge. Observed peak is 1260.9 ls^{-1} with a simulated peak of 1815.0 ls^{-1} giving a reduction in peak of 345.9ls^{-1} (16.0%). This suggests that if more bunds were installed within the Potwell Dyke catchment, more storage would be available and significant reductions in peak discharge could be achieved.

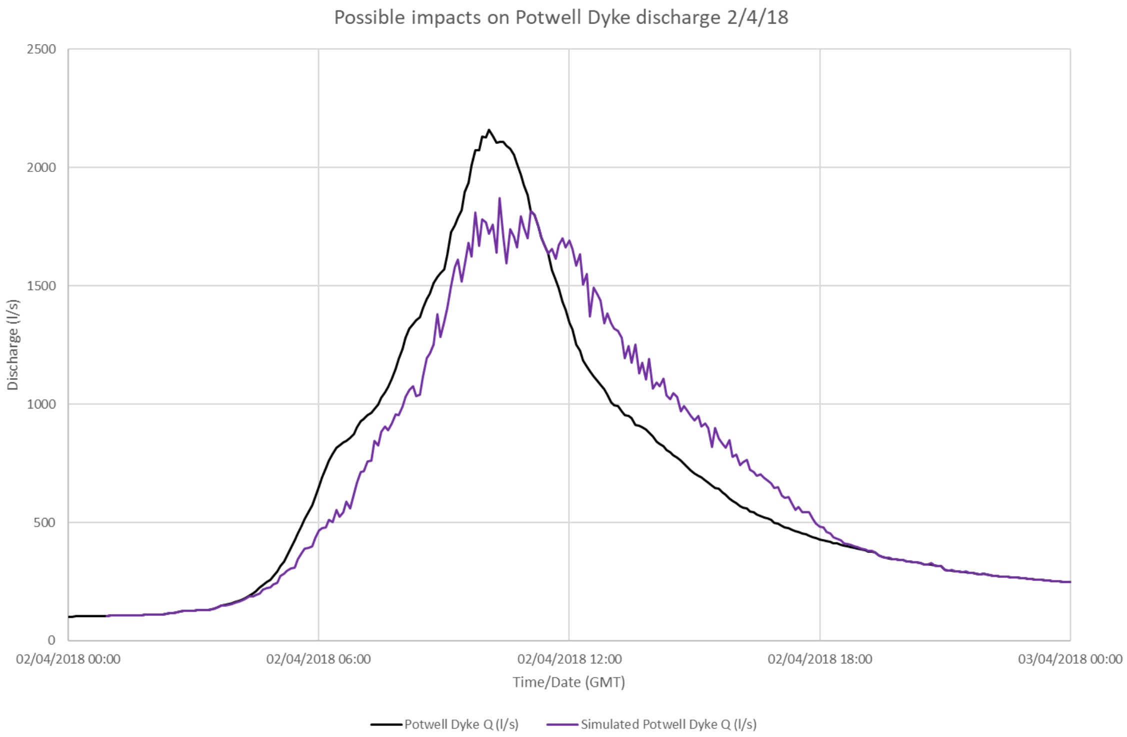

Figure 5.61 Potwell Dyke discharge 2/4/18 using Common mere storage multiplied by 20.

5.4 Discussion

5.4.1 Hydrological data

In total, 28 events were selected for analysis of hydrograph parameters, based on a 10cm rise in water level at the Lower Springfield Dumble logger. As previously stated, 10cm was chosen as the LWD dams were installed to allow flows of less than 10cm to pass underneath them, and so would only become active after this water level was exceeded. The data includes both pre and post intervention events for comparison.

Data collection occurred during drier than average years, with the 2016-17 and 2017-18 hydrological years having lower than average total annual rainfall (Table 5.7). Whilst this has not been ideal, discharge was recorded during several high flow events. Pre intervention, two events surpassed $1m^3s^{-1}$ within the Potwell Dyke, with one of the events exceeding $2m^3s^{-1}$. Post intervention, four events were recorded which exceeded $1m^3s^{-1}$ within the Potwell Dyke, with two exceeding $2m^3s^{-1}$. It must be noted that none of the events recorded during the period of this research were significant enough to cause fluvial flooding within the town of Southwell.

Individual event hydrographs in section 5.3.1 show that the Potwell Dyke, Springfield Dumble and Parklane Dumble all have flashy catchments, with lag times under one hour recorded within all three watercourses. This evidence, combined with clay soils within the catchment, a majority of arable land use which would increase soil compaction and reduce infiltration rates within arable land, suggests that overland flow is a key mechanism in runoff generation (Nicholson *et al* 2012; O'Connell *et al*. 2007). Therefore, the bunds are suited to this catchment as they aim to capture overland flow.

5.4.2 Changes in hydrograph parameters

There is evidence to suggest that post NFM intervention, LSD Peak discharge has been reduced (Figure 5.41). However, reductions may be less effective during higher magnitude events. Figure 5.41 gives evidence to support this, as the post intervention stage trendline curves towards the pre intervention trendline. The post intervention trendline is calculated to intercept the pre intervention one at an LSD stage of 0.486m which would represent a discharge of $3111.6ls^{-1}$ using the LSD rating curve in Figure 5.23. As discharge has not been measured at this stage within the Springfield Dumble, extrapolating these results may be subject to greater uncertainty.

Furthermore, as the 2/4/18 and 10/4/18 events are observed to be a closer fit to the pre intervention trendline, the impact of NFM on the hydrograph may diminish well before a peak discharge of $3111.6ls^{-1}$ within the Springfield Dumble. This finding is supported by literature which states that the impacts of NFM will decrease as event magnitude increases (Marshall *et al.* 2019: Archer Bathurst and Newson 2016; Dadson *et al.* 2017; Burgess-Gamble *et al.* 2017). However, many of these studies focus on land management methods of NFM such as afforestation and soil improvements. A study by Quinn *et al* (2013) suggested that to have a significant impact on peak discharge during high magnitude events, a greater amount of storage is required than has been installed within the slope scale of this study. Therefore, if more storage was available, the higher magnitude events may fit closer to the post intervention trendline. However, it is important to remember the barriers to NFM implementation discussed previously, as increasing available storage within the catchment depends on the decisions of private land managers and so may not be possible in a real-world situation.

Statistical analysis has shown no significant difference between pre and post intervention mean hydrograph parameters within the Springfield Dumble or the Parklane Dumble. Within the Potwell

Dyke, pre and post intervention mean time to peak and also time to recede were found to have a significant difference. Mean post intervention peaks as wells as time to recede were found to be longer than those during pre NFM intervention events. The limited findings here may reflect the sample size, which reduces the power of statistical analysis combined with complex nature of catchment hydrology (Wingfield *et al,* 2019; Lane, 2017; Pattinson and lane, 2011). With reference to the significant findings indicating change within the Potwell Dyke hydrograph parameters, this may be due to other catchment parameters such as antecedent soil moisture being low as result of the drier than average year (Iacob *et al.* 2017). Given that this research has implemented NFM at a subcatchment scale and no significant changes have been found at that scale through statistical analysis, it would be unreasonable to suggest that NFM has significantly changed mean hydrograph parameters at the Potwell Dyke scale.

The findings from statistical analysis reflect the complex nature of identifying a signal of change from data in a catchment where multiple factors may influence the change itself. Factors such as different antecedent conditions, land use change outside of the experiment, the fact that no two rainfall events are the same and hydrological science being uncertain in itself, mean that picking out changes in the hydrograph as a result of NFM implementation remain difficult. This has also been discussed within relevant literature (Lane 2017; Pattinson and Lane, 2012).

5.4.3 Temporary water storage in bunds

Gauged bunds stored the largest percentage of peak discharge recorded during this research. During the 30/12/17 event, both the Common Mere and 2nd Sunnydale bunds were observed to capture a large percentage of discharge, with Common Mere storing a maximum of 28.0 ls^{-1}. The cumulative storage of the bunds reduced peak flow at LSD by 32.5-38.9ls^{-1} (32.5-38.2%) within the Springfield Dumble. Data from this event shows a change in hydrograph shape, with water shifting from the rising limb and peak of the simulated hydrograph, to the falling limb of the observed hydrograph. The change in hydrograph shape proved evidence that NFM shifts discharge to the falling limb from the rising limb and peak, as discussed by Thomas and Nisbet (2007). An experiment by Wenzel *et al*. (2014) had similar results, as their findings indicated that storage created by LWD dams shifted the shape of the hydrograph. Therefore, NFM intervention within this study has been shown to have the potential to alter the shape of the hydrograph and reduce peak flows.

During the same event within the Parklane Dumble, although the bund did become active in storing water, the impacts on peak flows were more limited with peak discharge reduced by 0.8ls^{-1} (0.5%). This may perhaps be explained by several factors including the bund being bypassed by overland flow or spatial variance in rainfall between both subcatchments (Shaw *et al,* 2011). During the 2/4/18 and 10/4/18 events the bund reduces peak flow at LPD by 1.9 ls^{-1} (2.9%) and 3.5ls^{-1} (16.3%) respectively. These storage values and consequent discharge reductions are much smaller than those observed within the Common Mere bund and Second Sunnydale bunds during the same event. Therefore, the Parklane bund may only become active in storing a greater amount of water if a higher magnitude rainfall event occurs. Although it can be said that the active storage within the Parklane bund is limited, the importance of having available storage within NFM interventions is highlighted within the literature (Nicholson *et al*. 2012). In turn, the Parklane bund may have an impact on peak discharge during higher magnitude rainfall events where a greater amount of overland flow is generated, and therefore water is attenuated by the bund.

Results show that each bund functioned differently during events, so it is important that bund location is selected appropriately to make sure that they are located where they can effectively store overland flow. The changing storage of each bund during the 30/12/17 event has shown that

Common Mere is the most efficient bund at storing water, having a maximum storage rate of 28.0ls^{-1} during the event. Second Sunnydale had a maximum fill rate of 5.5 ls^{-1} with Micklebarrow Springfield filling at 6.3-11.5ls^{-1}, depending on which gauged bund water level data were used to calculate the estimated storage. During this event the 1st Sunnydale bund did not store water due to its catchment size being below the threshold at which overland flow is greater than the flow out of the outlet pipe.

Gauged bund changing storage and LSD discharge data from the 2/4/18 event shows that the bunds were active throughout the event and did not plateau. If they had plateaued, that would have suggested they overtopped and did not store water during the peak of the event. However, it has been shown that the bunds were still active in storing water during the peak discharge of Springfield Dumble and so reduced peak discharge. This highlights the importance of the availability of storage during peak stream discharge. If impacts on peak discharge are to be made, interventions which store water need to have available storage during the stream hydrograph peak.

However, the maximum changing storage of the bund has been found to not coincide with the peak of LSD during some events. This may be due to the runoff process active within the catchment. As bunds only become active when overland flow is generated, reductions of peak discharge only occur when overland flow occurs and so reduces the overland flow element of the hydrograph. Therefore, the rate of storage of a bund is highly indicative of the overland flow generation within the bund catchment. Overland flow during intense rainfall events can be the first element of runoff to impact on hydrograph generation, especially within impermeable soil dominated catchments (Shaw *et al.* 2011), like are present within this study. Although the bunds may be storing water during the later throughflow element of the hydrograph during such events, they may be less effective at storing water during peak discharge and so have less of an impact on peak flows within the Springfield Dumble. This shows the importance regarding timing of storage during events if maximum reductions in peak discharge are to be achieved.

As previously discussed, during the 30/12/17 event, a moderate intensity period of rainfall was recorded with a 4.6mm antecedent to peak rainfall (Appendix A). With 7.8mm of rainfall falling over 229 minutes and rainfall events observed on the 26th and 29th of December, the event characteristics include a short total event time with moderate 60 minute rainfall onto soils which have been subjected to antecedent rainfall. As a result, the threshold for overland flow generation was reached before the watercourse peak discharge, with the maximum water storage within the bunds taking place during the rising limb of the observed hydrograph, rather than during the peak. Although the bund is still effectively storing water, it would be more efficient if maximum storage occurred during the flow peak. However, as certain events may cause overland flow to be the first element of runoff to impact on discharge, targeting the peak flow more efficiently may not be achievable. A key finding is made here in that the effectiveness of the bund in reducing peak flows is dependent on the pattern and intensity of rainfall during the event, not just the total event rainfall.

This pattern is also observed during the 10/4/18 event, with bund storage peaking before peak discharge at the LSD logger. However, on the 2/4/18 peak bund storage and peak discharge at LSD coincide. This is due to overland flow occurring at a greater rate during LSD peak discharge. Therefore, individual bund storage during a given event is highly dependent on catchment characteristics, antecedent settings and rainfall patterns. This highlights the complexity of water storage over both time and space. Each individual bund functions differently, and the same bund may function differently during a different rainfall event when rainfall patterns or catchment conditions differ. As NFM projects may suggest the amount of water storage available as a total, it is important that more detailed analysis of the availability and timing of water storage offered by an individual intervention is undertaken if NFM is to have a significant impact on the hydrograph.

Events on the 2/4/18 and 10/4/18 allowed for the analysis of water storage within bunds during higher magnitude events. It has been found that these events may be closer to the point at which NFM interventions are overwhelmed and so have a limited impact on peak discharge. Peak discharge at the LSD logger was higher during the 2/4/18 event when compared to that on the 10/4/18. The percentage decrease as a result of bunding is lower during the higher magnitude event on the 2/4/18. Therefore, for higher magnitude events, the percentage of reduction of peak discharge that NFM intervention causes decreases. However, during the 2/4/18 event, the total reduction of peak discharge was lower than that during the 10/4/18 event. Therefore, variations in overland flow generation between both events may also explain why the percentage of peak discharge stored is lower.

For all other events in this study, which have a smaller magnitude, little or no impact was made on the stream hydrograph of the larger catchment. This is similar to the findings of Odoni and Lane (2010) who, through their modelling study based a Pickering, showed that the effectiveness of NFM features increased as event magnitude increased. Although this has been observed within this study, evidence from this research discussed previously as well as current literature suggests that the effectiveness of NFM decreases as event magnitude increases (Archer Bathurst and Newson 2016; Dadson *et al.* 2017). Given that a hydrological threshold needs to be reached in order to generate overland flow and that the LWD dams are designed to let lower flows pass unimpeded. It is reasonable to suggest that there is a threshold that needs to be overcome before NFM interventions become active. It is important that this threshold is well understood so that the storage potential of individual features is available during the peak of high flow events.

During the 9/2/18, 12/3/18 and 13/4/18 events, peak discharge within the Potwell Dyke is shown to be increased slightly as a result of water discharge from the bunds. This is due to bund discharge from the Springfield Dumble catchment bunds occurring during peak discharge at the Potwell Dyke logger. This may be due to delays between peak overland flow and peak throughflow within the hydrograph. As catchment size increases, literature suggests that lag time also increases (Davie, 2008). As the bunds have been observed to have a maximum storage prior to the peak stream discharge within the subcatchment, when upscaling to the larger catchment, this may mean that drainage from the bund occurs during peak discharge of the Potwell Dyke catchment and so discharge increases. Within this research, this has been found to be minimal and occurred during low magnitude events, with longer lag times, which are not a concern for the town of Southwell. During higher magnitude events, a shorter lag time means that the bund is still actively storing water during Potwell Dyke peak discharge. This highlights the importance of the timing of storage within NFM interventions when positive impacts for flood risk are sought and unforeseen negative impacts avoided.

As would be expected, a lesser impact in peak discharge reduction percentage occurred when scaling up from the smaller subcatchment scale to the larger catchment scale of the Potwell Dyke. For events analysed, reductions diminish when compared to those achieved at LSD. For example, during the 30/12/17 event, total reduction from Potwell Dyke peak discharge was calculated at 16.7-17.8 ls^{-1} (1.7-1.9%) whilst reduction on the Springfield Dumble was calculated at 30.3 - 39.8 $^{ls-1}$ (32.5 – 38.2%). Although the bunds have had a significant impact at a slope scale (Springfield Dumble), at a catchment scale where peak discharge is greater, the percentage of reduction in peak discharge decreased. This supports the argument that as catchment size increases, the FRM benefits of NFM interventions decrease. Current literature has suggested that, at the larger catchment scale, the complexities of the catchment may mean that impacts on peak flows by NFM may be insignificant (Archer, Bathurst and Newson, 2016). The results of this study support this, as it was found that the percentage of discharge reduction at Potwell Dyke does not exceed 1.9%. Therefore, as catchment scale increases, discharge also increases and so NFM interventions may not provide enough available storage to have a significant impact on peak flows at larger scales.

Some studies suggest that if more available storage was created within the catchment, impacts at a larger catchment scale could be significant. For example, Quinn *et al.* (2013) state that 19,250m^3 of storage is required within a 10km^2 catchment to have a significant impact on peak flows. More available storage could have a significant impact on the peak flow at the Potwell Dyke catchment scale. Using data collected from the Common Mere bund during the 2/4/18 event, a simulated storage value was applied to the Potwell Dyke discharge based on 20 bunds, acting as Common Mere did but with optimal storage during Potwell Dyke peak discharge. This resulted in a 345.9 ls^{-1} (16%) reduction in peak discharge. The increased storage also has a significant impact on the hydrograph shape. As a result, this indicative evidence suggests that increasing the amount of available storage within the catchment could have a significant impact on the hydrograph.

5.5 Conclusions

A change in the stage relationship between the USD and LSD logger has been found post NFM intervention. Stage at the LSD logger has been found to be lower post NFM, when compared to data from pre NFM events. This is particularly noticeable during the 30/12/17 event where stream discharge at LSD was significantly reduced by water storage in the bunds. Although a reduction in stage has been found, the events of the 2/4/18 and 10/4/18 provide evidence to suggest that as event magnitude increases, impacts on stage and discharge decrease. When comparing pre and post NFM USD and LSD relationships, these two events are a closer fit to the pre intervention trend line suggesting that the impact on peak discharge during events of this magnitude may diminish.

Statistical testing of stream hydrograph parameters has been found to be inconclusive. This may be due to the lack of data gathered which reduces the ability to detect change. While this is considered as a null result, it highlights the difficulty in hydrological studies of NFM and the current ability to detect change. As there are many variables impacting on hydrograph shape both spatially and temporally, and such variables are unlikely to be fixed during the timescale of hydrological monitoring, it will be difficult for future projects to use statistical testing to detect change without a significant amount of both pre and post intervention data.

The analysis of individual bund storage during rainfall events has allowed for detailed analysis of the impact of offline storage on the hydrograph. This method has allowed for empirical data to be used to inform a basic model to predict ungauged bund storage. Whilst this method does have its limitations, it gives some insight into the possible impacts of multiple storage areas across a catchment on the hydrograph. Findings from this method show that during the event on the 30/12/17, the hydrograph shape changed due to water storage in the bunds, with discharge shifting from the rising limb and peak, to the falling limb. As a result, a reduction in peak discharge has been found during the events analysed at the subcatchment scale. This fits with current theory discussed within the literature (Thomas and Nisbet, 2007). The detailed analysis of bund performance has also highlighted that each bund impacts differently on peak flows due to variations within catchment parameters and variation in rainfall patterns between events. This is an important consideration for NFM practitioners as careful design which considers possible overland flow paths and catchment sizes for each intervention, is crucial if available storage is to be maximised. The detailed analysis has also allowed for further discussion on the importance of available storage during rainfall events. During all events recorded, at the subcatchment scale, the bunds were storing water during the peak of the watercourse. This is imperative as NFM interventions which are full during the peak of an event are not actively storing water, and so have a very limited if negligible benefit to FRM.

During the two highest magnitude events recorded, (2/4/18 and 10/4/18) positive reductions in peak discharge were found. However, for these larger magnitude events the reductions in peak discharge as a percentage were lower. This presents further evidence to suggest that the FRM benefits during larger magnitude events may be limited. Future work should consider this and aim to capture data during higher magnitude rainfall events to assess the impacts of NFM the hydrograph during such events.

Upscaling to a larger catchment scale has been found to reduce the impact of NFM on peak discharge. The impacts on Potwell Dyke discharge as a result of NFM intervention within the two subcatchments was found to be limited, with a 1.9% reduction being the highest reduction in Potwell Dyke peak discharge observed. Although this is a limited impact, the data suggests that positive impacts have been made. Through further analysis, it is concluded that additional storage within the Potwell Dyke catchment could significantly reduce peak discharge within for the higher magnitude events sampled. Furthermore, it was found that more storage could have impacts on the hydrograph shape, shifting a greater amount of discharge from the rising limb and peak to the falling limb.

An important conclusion is that when targeting overland flow using NFM features, reductions in peak discharge may not be as effective as is possible. Depending on the characteristics of the rainfall event and the catchment antecedent setting, storage of overland flow may be at its greatest during the early stages of the hydrograph and so the impact on peak discharge may be less. Positive storage during watercourse peak discharge was observed during all events sampled at the subcatchment scale. However, the timing of storage could be a significant issue in catchments where short duration intense rainfall results in a double peak hydrograph, consisting of a peak caused by overland flow and one caused by throughflow. In this instance, the bunds may store water during the peak caused by overland flow, and then release it during the second peak caused by throughflow. A similar finding has been discussed using data from the Potwell Dyke, where peak discharge during lower magnitude events has been increased as a result of NFM intervention. It has been discussed that this may be due to upscaling and the longer lag times that result. Whilst overland flow has been stored within the subcatchments, the consequent discharge of the bunds has occurred during peak discharge on the Potwell Dyke. It can be argued that this has only occurred during low magnitude events which present little to no risk, and that during higher magnitude events positive impacts on peak discharge have been found. The timings of discharge from NFM features should be an important part of the design of NFM features in future projects. The impacts of tributary synchronisation have been discussed within the literature (Pattison and Lane, 2011), but the timings of stream peak discharge and bund discharge have not been discussed and so further work should focus on this potential issue.

This study has used empirical evidence within its analysis to provide results which will help to inform future NFM projects. Such evidence can be used to inform design and discuss expected impacts on the hydrograph. Within the literature, the collection and analysis of empirical evidence is limited (Wilkinson *et al*. 2019), and so the findings of this research provide a valuable addition to the current evidence base. The research has shown that whilst there are some limitations to impact on the hydrograph when event magnitude and catchment size increases, positive impacts have still been made. As a result, NFM is concluded to have a part to play in catchment based FRM approaches if sustainable IFRM is to be achieved.

6 Attitudes of flood-affected community residents towards Natural Flood Management

6.1 Chapter Introduction

Popular media reports after the 2015 winter flooding events suggested that NFM could help to reduce flood risk, and that the UK public wanted more NFM and working with natural processes to reduce flood risk (Hankin *et al.* 2016). For example, newspaper articles such as that written by Monbiot (2015) discussed that flooding had been subsidised by paying land managers to drain their land as quickly as possible which creates greater flooding for downstream communities. Monbiot (2016) also suggested that if river systems were more natural with functioning floodplains, downstream structural measures may not become overwhelmed. Moreover, Carrington (2016) wrote within the Guardian that although the government support NFM, funding for measures was still lacking. Although dredging after flood events has been called for by media in the past (Telegraph, 2014), the focus of the media following the winter 2015 storms had changed. Due to public desire for alternative FRM measures, the Department for Environment, Food and Rural Affairs (DEFRA) committed £15m for NFM projects in order to build the evidence base of NFM as a FRM measure (Leadsom, 2016).

Literature has shown that acceptance of NFM projects can increase through interactions between flood management practitioners and stakeholders (Cornell, 2006; Waylen *et al*. 2017). Engagement with local communities can give greater success during decision making within FRM projects, as they are given some ownership over the processes and outcomes of a scheme (Thaler and Levin- Keitel, 2016; Tseng and Penning-Rowsell, 2012). Moreover, problems can arise when authorities do not power share and so do not include local knowledge within planning. For example, Lane *et al*. (2011) suggested that a breakdown can occur between the public and FRM practitioners, if it is felt that local knowledge is being dismissed. As most FRM projects will encounter opposition and cause conflict, stakeholder engagement is key to overcome this (Tseng and Penning-Rowsell, 2012).

Despite this, little is yet known about the attitudes of communities affected by flooding towards NFM, and so there could be limited success of engagement activities if these are not considered. In turn, this may present a barrier to NFM uptake, so research is required to assess the factors that impact upon a flood-affected communities' attitude towards NFM. As such, in this study we aim to investigate this research gap and assess the attitudes towards NFM of residents within a flood-affected community in the UK and the factors that affected their attitudes.

6.2 The flood affected community

As previously discussed within the study site Chapter, Southwell has a history of flooding with two recent events (2007 and 2013) causing flooding within the town. The study site therefore offers valuable opportunity to assess the flood affected community's attitudes towards potential NFM intervention, alongside the factors that affect their attitudes.

According to the Office for National Statistics UK 2011 census (2016), Southwell has a population of 7,297 with a mean age of 44.4 years. Residents are mainly white (97.6%), with 26.2 % of occupants in a professional occupation and 14.4% within managerial or director roles. 41.2% of residents have an education qualification higher than level 4 (higher than one year of university study), so Southwell reflects an affluent and educated community.

Within this research, barriers to the uptake of NFM are analysed from multiple perspectives using physical and social based methods. Whilst hydrological research set within physical geography can help to address evidence gaps and drive new field based knowledge, human geography can help us to begin to explore the constraints to uptake, local community favourability and how to increase stakeholder involvement within NFM projects (Nesshover *et al*. 2017).

This new approach is needed within NFM studies to explore the complex interlinked barriers to NFM. Hadorn *et al*. (2006; 120) suggests " *To produce reliable knowledge for societal strategies about future possible developments, research has to reflect the diversity, complexity and dynamics of the related processes as well as their variability between concrete problems*". As this study uses methods from both physical and human geography based studies, it provides a holistic overview of the current barriers to NFM uptake and implementation.

6.3 Methods

A questionnaire (Appendix D) was sent to all households in Southwell (n=2,901) in a census-style strategy in July 2016. Questionnaires were distributed together with a resilience handbook, created by the Southwell Flood Forum. A response rate of 7% (n=204) was achieved. The handbook contained a short article written by the first author of this thesis (Appendix E), which focused on the implementation of NFM and its effects on flood risk.

To assess Southwell residents' attitudes towards NFM, they were asked to indicate their extent of agreement or disagreement with eight statements relating to NFM (Table 6.1). The statements were selected from the findings of the literature review. For example, Bracken *et al*. (2016) found an overwhelming desire for more natural methods within FRM. Ruiz-Villanueva *et al.* (2018) found that communities did not base their views on FRM measures on past experience, but more on the naturalness of the intervention and Buchecker (2016) found that respondents who had been previously flooded were more likely to favour engineered FRM. The responses were measured on a five option Likert scale, including Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree. Both positive and negative statements were used. Responses to positive statements were coded as: SD= 1, D=2, N=3, A=3, SA= 5. A reverse scoring was used for negative statements. Scores on each of the eight items were then summed in order to obtain the total attitude score of an individual respondent. Based on the summated scores, residents' attitudes to NFM were then split by quartile distribution and categorised into unfavourable (scores 0- 26), somewhat favourable (scores 27-29), and favourable (scores 30-40), to give groups of comparable size.

Table 6.1 Attitude statements used in the questionnaire.

Attitude statements
1: Natural Flood Management is a viable option to reduce flood risk (+ve).
2. I would prefer Natural Flood Management in my area when compared to structural measures (+ve).
3: Natural Flood Management is expensive compared to other flood risk management strategies (-ve).
4. Current UK flood risk management policy promotes the use of Natural Flood Management (+ve).
5. More research needs to be done to prove that Natural Flood Management can reduce flood risk (-ve).
6. Natural Flood Management can increase flood risk (-ve).
7. Natural Flood Management can provide wider benefits beyond flood risk management e.g. wildlife benefits (+ve).
8. More funding should be allocated for Natural Flood Management (+ve).

In order to identify the factors that affect residents' attitudes, seven independent variables which were identified and selected from a literature review, were included in the questionnaire. These were: knowledge, gender, age, previous flood experience, income, education level, and length of residency. The knowledge variable was measured by asking the respondents an open ended question – *what does the term Natural Flood Management mean to you*? The answers were then compared against the SEPA definition of NFM (see below) and, accordingly, categorised as either "incorrect/ no response", "partially correct" and "correct".

> "*Natural Flood Management involves techniques that aim to work with natural hydrological and morphological processes…these techniques include the restoration, enhancement and alteration of natural features and characteristics…*" (SEPA, 2016;6).

The data were analysed using SPSS software. Descriptive statistics were calculated for each variable in order to assess the attitudes statements. An ordinal regression test was used to test for significant relationships between respondent demographics and summative attitude.

6.4 Results

The questionnaire was sent to all households in Southwell (n=2,901) with a response rate of 7% (n=204) achieved. Results are presented in Table 6.2. The respondents had a mixed profile, with a nearly even proportion of males and females in the sample. The majority of the respondents were between the ages of 51-70 years. A large proportion of respondents had an education level equal to or higher than level 4. With nearly one third of the sample having a post-graduate education, the sample indicates a highly educated community. Only 13% of respondents had experienced flooding in their household, which is to be expected as flooding occurs at a small spatial scale when compared to the town as a whole. For example, as a consequence the 2013 flood, 253 properties out of 2901 experienced interior flooding and so 9% of properties experienced interior flooding during this event (URS, 2015). Over two thirds of the respondents were found to have been residents within the town for over 10 years, meaning that they would have been resident within the town during flood events in 2007 and 2013.

From Table 6.2, it was found that a high percentage of the respondents were favourable towards NFM (scores 30-40) or somewhat favourable (score 27-29), but with 30% unfavourable (scores 0-27). However, the results demonstrate a lack of knowledge of NFM within the sample. When asked what natural flood management means to them, 27% of respondents gave a correct answer, 25% gave a partially correct answer and 48% of respondents did not respond or gave an incorrect answer.

From Figure 6.2, support for NFM was found within the results as 76% of respondents agreed or strongly agreed that NFM is a viable option to reduce flood risk. It was found that respondents prefer NFM over structural measures, with 55% either agreeing or strongly agreeing and only 6% disagreeing or strongly disagreeing to preference of NFM over structural measures within their area. Respondents also indicated that NFM can provide wider benefits beyond FRM with 37% of respondents agreeing and 30% strongly agreeing. Furthermore, respondents suggested that they would like to see more funding directed towards NFM with 36% agreeing and 19% strongly agreeing and only 5% or respondents disagreeing or strongly disagreeing.

A lack of knowledge on some aspects of NFM has been acknowledged within the sample (Figure 6.1). When asked if NFM is expensive compared to other FRM strategies, 58% did not know or were neutral and 31% disagreed or strongly disagreed, 7% agreed or strongly agreed. Additionally, when asked if NFM can increase flood risk, 39% did not know or provided a neutral response, 5% agreed or strongly agreed and 39% disagreed or strongly disagreed. A lack of understanding of policy relating to NFM was found as 70% of respondents did not know or gave a neutral response when asked if UK FRM policy supports NFM. Finally, results suggest that the community feel more research needs to be done to prove that NFM can reduce flood risk as 37% of respondents agreed and another 11% strongly agreed with this statement.

The bivariate graph in Figure 6.2 shows that a large proportion of respondents who were unfavourable towards NFM gave no answer or an incorrect answer to the knowledge test. Similarly, Figure 6.3 demonstrates that unfavourable respondent’s category had the highest number of respondents who also had previous flood experience.

Table 6.2 Respondents profile

Variables	Frequency	Percent
Attitude		
Favourable	77	38
Somewhat favourable	66	32
Unfavourable	61	30
Respondent demographics		
Age		
18-50	50	25
51-70	88	44
71+	62	31
Gender		
Prefer not to say	2	1
Male	102	52
Female	93	48
Education		
Level 1-3 (School)	21	15
Level 4-6 (Undergraduate)	74	52
Level 7-8 (Post Graduate)	47	33
Income		
up to £42,999	104	71
£43,000+	42	29
Length of residency		
Less than 10 years	66	33
Over 10 years	134	67
Previous flood experience in the household		
Yes	27	13
No	175	86
Knowledge of NFM		
No response/incorrect	98	48
Partially Correct	51	25
Correct	55	27

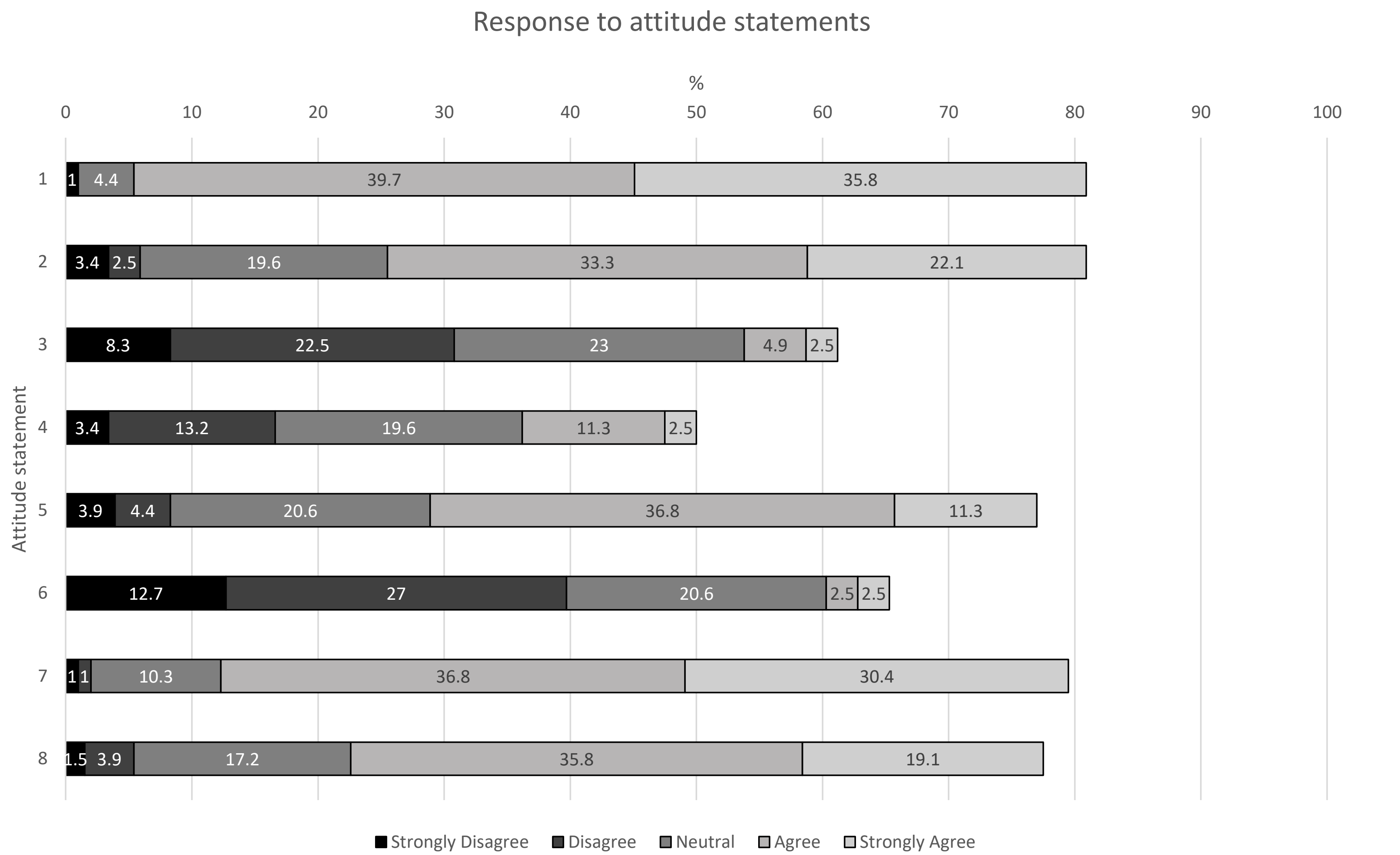

Figure 6.1 Response to individual attitude statements (attitudes statements shown in Table 6.1). N=204 for all attitude statements. "Do not know" and "no response" have been removed from this figure.

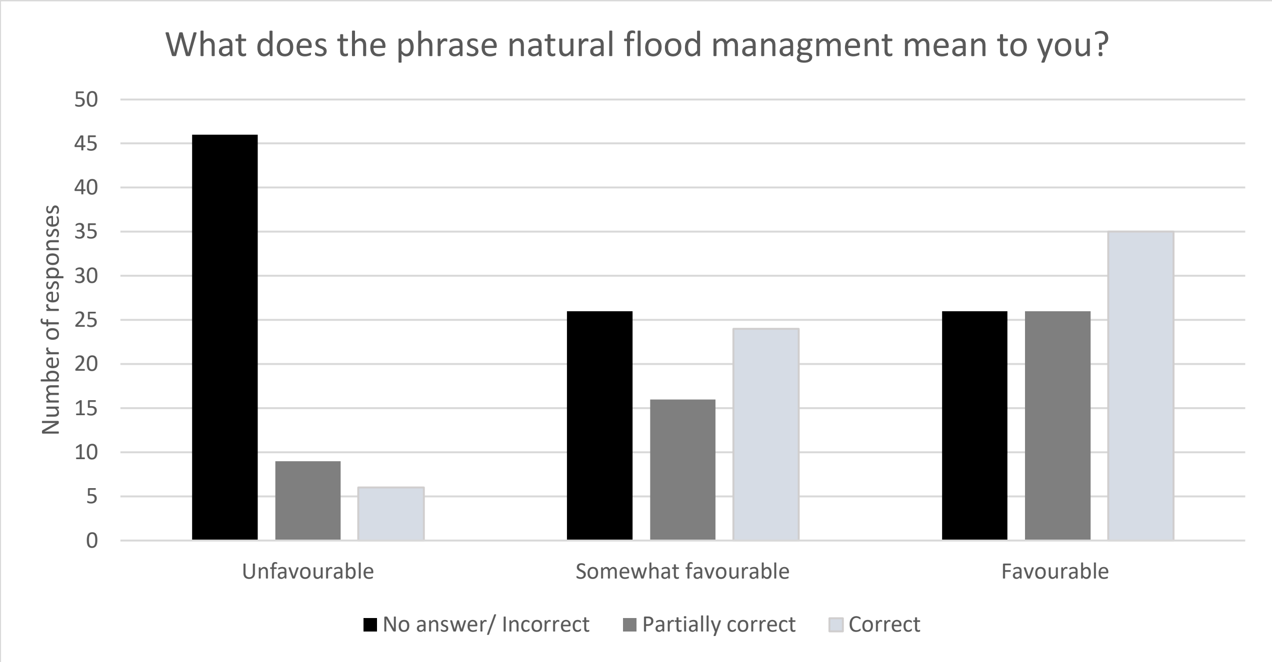

Figure 6.2 Bivariate graph of respondents' knowledge and favourability of NFM

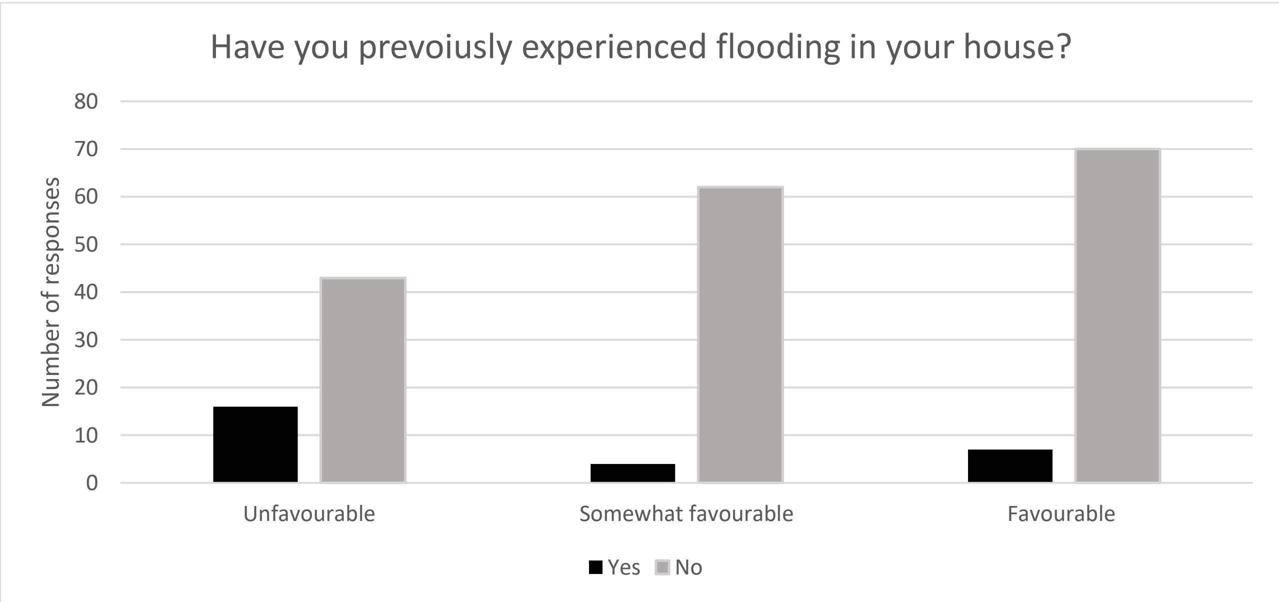

Figure 6.3 Bivariate graph of respondents' previous flood experience and favourability towards NFM.

Table 6.3 Ordinal regression showing affects of the independent variables on attitudes to NFM.

	Coefficients	Standard Error	Significance
Education level 1-3	-0.707	0.617	0.252
Education level 4-6	-0.03	0.443	0.946
Education level 7-8	Ref. category		
Residency less than 10 yrs	-0.537	0.467	0.25
Residency more than 10 yrs	Ref. category		
Income £0-42,999	-0.659	0.467	0.158
Income £43,000+	Reference		
Knowledge incorrect	**-1.117**	**0.486**	**0.022***
Knowledge partially correct	0.357	0.494	0.471
Knowledge correct	Ref. category		
Age 18-50	0.177	0.63	0.779
Age 51-70	-0.206	0.53	0.698
Age 71+	Ref. category		
Gender Male	-0.015	0.405	0.97
Gender Female	Ref. category		
Previous flood experience	**-1.16**	**0.528**	**0.028***
No previous flood experience	Ref. category		

The results from the ordinal regression test (Table 6.3) show that incorrect knowledge of NFM and previous flood experience of the respondent had significant negative effects on the respondents' attitude towards NFM. This means that those with incorrect knowledge are significantly more likely to have an unfavourable attitude towards NFM when compared to the reference category. This is similar with respondents who have previous experience of flooding in their property. These respondents are also significantly more likely to have an unfavourable attitude towards NFM. The model was a good fit to the data with a significant improvement over the intercept only model (-2LL for intercept only model is 202.936 and for the final model is 180.690, which is significant at $p<0.05$ level; Goodness of Fit statistics were not significant at $p>0.05$). Pseudo R-square values show that the model explains between 18.5% (Cox & Snell) and 21% (Nagelkerke) of the variance in respondents' attitudes towards NFM. The odds ratios for incorrect knowledge was 0.33 and for previous flood experience 0.32, meaning that those who had incorrect knowledge previous flood experience were around 70% (rounded) less likely to have a favourable attitude to NFM.

6.5 Discussion

6.5.1 Attitudes towards NFM

Descriptive statistics showed broad support for NFM from respondents. For example, 40% of respondents agreed and 36% strongly agreed that NFM is a viable option to reduce flood risk (Figure 6.1). When asked if the respondent would prefer natural flood management in their area when compared to structural measures, only 6% strongly disagreeing or disagreed (Figure 6.1), which shows further support for NFM over structural measures. Additionally, respondents suggested that they would like to see more funding directed towards NFM intervention within their catchment, further indicating support. The results demonstrate that there is a support for NFM within the at-risk community, and aligns with the results of Bracken *et al*. (2016) who found an overwhelming desire for alternate FRM methods rather than just structural methods within the surveyed community.

However, a lack of knowledge on some aspects of NFM have been found within the results. A majority of respondents did not know if NFM was expensive compared to other FRM measures. As NFM interventions are generally cheaper than structural FRM measures (Burgess-Gamble *et al.* 2017), results indicate that deeper understanding of NFM and its use within FRM is not well understood by respondents. This indicates a gap in the surveyed community's knowledge.

A lack of knowledge was also found relating to the community's understanding of policy which supports NFM intervention. Although some aspects of NFM policy are lacking, such as provision for future maintenance and liability for interventions, there are several policies such as the WFD (2000), Pitt review (2008) and Flood and Water Management Act (2010) which actively support the use of working with natural process to reduce flood risk whilst promoting ecological gains. The lack of knowledge of policy by the community may be a concern as the Environment Agency aims to devolve some power for FRM to communities (Thaler and Levin-Keitel, 2016). If a community would like NFM within their catchment, but do not have the knowledge to apply policy to practical intervention, a barrier to uptake may be created as the capacity for intervention is reduced. Thus, the lack of knowledge reduces social capacity, which further hinders community level NFM intervention (Thaler and Levin-Keitel, 2016).

It has been found that most respondents either did not think that NFM can increase flood risk, which is in line with current literature, or did not know. Although the evidence base to support NFM is still building, it is generally held that NFM interventions are "no regret" interventions, unless tributary timings are synchronised (Wilkinson *et al.* 2014; Rogger *et al.* 2017). The results here show that there are still residents who do not know this or perceive that NFM can increase flood risk. This further supports the argument that community knowledge of NFM needs to be improved.

When asked whether more research needs to be done to prove that natural flood management can reduce flood risk, respondents generally agreed or strongly agreed. This is supported by most relevant literature (Burgess-Gamble *et al.* 2017; Cook *et al.* 2016; Bracken *et al.* 2016; Environment Agency, 2012) and highlights that, in order to improve public attitudes and reduce distrust towards NFM, more hydrological evidence is required. These results need to be communicated effectively with the public. However, it is important that caution is taken to manage expectations when communicating evidence. As NFM is generally thought to have less an impact on flood risk than structural measures, the two methods should be combined where necessary as NFM is often considered as complimentary to hard engineered FRM (Archer, Bathurst and Newson, 2016; Iacob, Brown and Rowan, 2017). It is essential that this point is communicated in a transparent manner to manage public expectations and reduce future conflict and mistrust.

Residents of Southwell recognised that NFM can have positive wider benefits. As such, these benefits should be communicated to at-risk communities in order to increase NFM project acceptance. For future projects, this is an important consideration for NFM practitioners. NFM aims to not only reduce flood risk but to bring wider benefits such as habitat creation, sediment capture and aesthetical gains (Burgess-Gamble *et al.* 2017). Such gains have been recognised to be viewed positively by the at-risk community. Communicating the possible wider benefits of a NFM project could improve community attitudes towards it. Therefore, this information should be disseminated to the at-risk community at the project outset.

6.5.2 Factors affecting attitudes towards NFM

A key finding within this research is that respondent demographics were found to have no significant association with attitudes towards NFM within the at-risk community. Instead, it has been found that attitudes towards NFM intervention within an at-risk community are significantly influenced by respondent's personal experience or their knowledge of NFM. This highlights that respondents did not hold views based on who they were, but on what they know and so a change in at-risk community attitudes towards NFM is possible.

A negative association between respondent's knowledge of NFM and attitude was found within the ordinal regression test. This has implications for uptake, as communities with a lack of knowledge of NFM may be less favourable towards it being part of FRM within their catchment. Everett *et al*. (2018) found that Blue Green Infrastructure, which aims to store water within urban green areas, was hindered by a lack of public knowledge. Literature has anecdotally suggested that a lack of knowledge of NFM may be a potential barrier to uptake of NFM (Barlow, Moore and Burgess-Gamble, 2014). However, few studies to date have measured and discussed the implications of public lack of knowledge on attitudes specifically towards NFM. Therefore, this finding adds new knowledge to the NFM literature. For future NFM projects, the findings of this research show that improving the local resident's knowledge may help to overcome the negative attitude towards NFM that a lack of knowledge can create.

A negative association was found between respondents previous flood experience and their attitude towards NFM. Within this survey, the ordinal regression results demonstrate that respondents who were previously flooded were more likely to be unfavourable towards NFM than those who had not experienced flooding within their property. This contradicts the findings of Ruiz-Villanueva *et al.* (2018) who stated that previous flood experience was not the main influence on attitudes. As NFM is generally thought to have less of an impact on flood risk than structural measures, at-risk respondents may be less favourable as they focus on improving their quality of life through proven flood risk reduction methods (Buchecker, 2016). This attitude may contrast with the respondents who have not been previously flooded, who may focus more on the recreational and aesthetical value of FRM interventions for their town (Fitton, Moncaster and Gurtherie, 2015). This is an important consideration for NFM project managers as NFM will be installed in areas which have experienced a previous flood event. As a result, residents may not be favourable towards NFM as they focus on proven flood risk reduction interventions, and so opposition may be present. To overcome this, clear communication is needed to explain the aims of natural flood management and that a preferred option is to complement structural measures with NFM to reduce flood risk.

6.6 Conclusions

Given the increasing importance of understanding about and engaging with local communities in NFM projects, this study aimed to investigate an at-risk community's attitude towards NFM intervention within their catchment. The findings indicate that a majority of respondents have a favourable or somewhat favourable attitude towards NFM interventions. Negative attitudes towards NFM have been found to be influenced by respondent's previous experience of flooding and knowledge of NFM rather than their demographics. In line with previous studies, previous experience of flooding in the respondent's home has been found to impact on attitudes towards NFM. This may be a result of an understandable focus towards structural FRM measures, which can significantly reduce flood risk and improve the flood receptor's quality of life. Those who have not had an experience of flooding may focus instead on the recreational and aesthetical gains that NFM has to offer.

This study has also revealed that, within a flood affected community, there are respondents who still lack knowledge of NFM. This has the potential to reduce the capacity and willingness of the local community to participate in NFM intervention. Importantly, it has been demonstrated that a lack of knowledge of NFM also has a negative impact on attitudes towards it, with respondents who had no knowledge, or who did not give a response, more likely to be unfavourable towards NFM. As a result, the knowledge of an at-risk community should be assessed and, if needed, information and appropriate education given in order to improve favourability of local residents towards NFM.

This study is the first to measure the attitudes of an at-risk community towards NFM. Literature has already suggested that community expectations of the outcomes of NFM intervention need to be managed. NFM is not recommended as a sole means of FRM for at-risk communities. Combining softer approaches with structural measures may increase favourability and acceptance of NFM by the local community, especially for those with past experiences of in-house flooding. This research highlights the negative impacts on attitude that can be associated with a lack of knowledge, so it is also important that NFM practitioners are open and transparent in communicating the predicted outcomes that intervention may have on flood risk in their community. More research is required to assess whether increasing community knowledge of NFM can help to improve attitudes towards its use within a catchment.

7 Barriers to the uptake and implementation of natural flood management: a social-ecological analysis

7.1 Chapter Introduction

Although it has been discussed that softer FRM measures are becoming increasingly common, few studies have been conducted to identify and assess the barriers to the uptake of NFM as perceived by stakeholders such as farmers or FRM practitioners (Holstead *et al*. 2015, Waylen *et al*. 2017; Rouillard *et al.* 2015). There is a growing realisation that the barriers to NFM uptake need to be identified using a broader, system wide approach (Thorne et al. 2015). Accordingly, in this chapter we apply a social-ecological systems approach (Ostrom, 2009) to identify the barriers to the uptake of NFM practices in the UK. The barriers are then assessed and discussed to give an insight into the potential challenges that other NFM projects may face. This chapter provides an opportunity to contribute to the existing literature by assessing the barriers from the viewpoints of both land managers and FRM practitioners, which has not been previously done within the literature.

7.2 Methods

In this study, twenty three interviews were undertaken. Seventeen with practitioners within UK FRM, and six with land managers within a catchment above Southwell, Nottinghamshire. The study site was chosen because NFM has been implemented recently by the authors as part of wider research within the local catchment. Interviews were used within this study as the qualitative data gathered would offer a richer data set to assess the complex barriers to NFM faced by interviewees (Silverman, 2004).

Of the 6 land managers interviewed, 1 did not actively farm their land and so the term “land manager” is used within this study to reflect this. Of the 17 practitioners, the associated sectors were as follows: statutory body (7), NGO (5), academic (2), local government (1) and consultancy (2). With regards to the land managers, the study has a small geographical reach as the interviews focus on land managers within Southwell only. However, the practitioners had a wider geographical reach across the UK. Land managers were interviewed in May/June 2016, with practitioners being interviewed between October 2016 and February 2017.

Practitioners were recruited through networking with further respondents selected though snowballing. They were selected on their knowledge of NFM, but also their wider knowledge of FRM governance. All but one of the significant land managers within Southwell were interviewed. Therefore recruitment was based on the land holding within the catchment.

Interviews were conducted either face to face or by telephone and were semi-structured as to give the respondent chance to elaborate on the emerging themes surrounding the barriers to NFM from their perspective. The interviews were steered by topic lists which was informed by current literature on the barriers to uptake of NFM (Appendix F and G). For land managers, the topic list included questions on what they thought NFM was, if they already had features on their land and what they perceived to the barriers to uptake to be on their landholding. Practitioner questions focused on what they perceived were barriers to land managers but also current constraints to implementation as a result of funding, policy and current governance. Interviews were recorded and transcribed by the interviewer. Transcripts were then imported into NViVo qualitative research software and were coded into the categories outlined within the analytical framework. Sub-codes where created to give more detail to emerging themes which would aid discussion. A matrix query within NVIVO was used to identify which of the barriers cited by land managers were also identified by practitioners.

Through the questionnaire used for data collection in Chapter 6, respondents were asked if they thought there were barriers to NFM, followed by an open ended question asking what the barriers were. This data has been included within this chapter as the results offer qualitative data and are closely linked to the barriers discussed by land managers and practitioners. There were 56 responses to the open ended question which asked what the barriers to the use of NFM are.

7.3 Analytical framework

For the sake of analysis we conceptualise a catchment facing flood risk management challenges as a socio-ecological system (SES) in which biophysical factors interact with social variables leading to desirable or undesirable outcomes. The SES framework that we use in this paper is adapted from the framework proposed by Ostrom (2009) (Figure 6.4). The framework is split into six categories: the governance system, actors, resource units, the resource system, interactions and finally outcomes. The governance system is defined as the specific rules surrounding natural flood management (NFM) implementation and how these rules are made (Ostrom, 2009). Actors relates to anyone who is involved with NFM implementation. For example, this could be an individual land manager, practitioner of flood risk management or member of the public (Nagendra and Ostrom, 2014). The resource system is the catchment itself. The resource system and research units have been combined, as it may be difficult to separate these two concepts analytically (Basurto, Gelcich, and Ostrom, 2013). Interactions can be interactions between actors, or actors and the biophysical system. Finally, outcomes are defined as what the outputs are of the system as a whole, for example, natural flood management uptake on farmland (Ostrom, 2009). Interview transcripts were coded under the five categories mentioned.

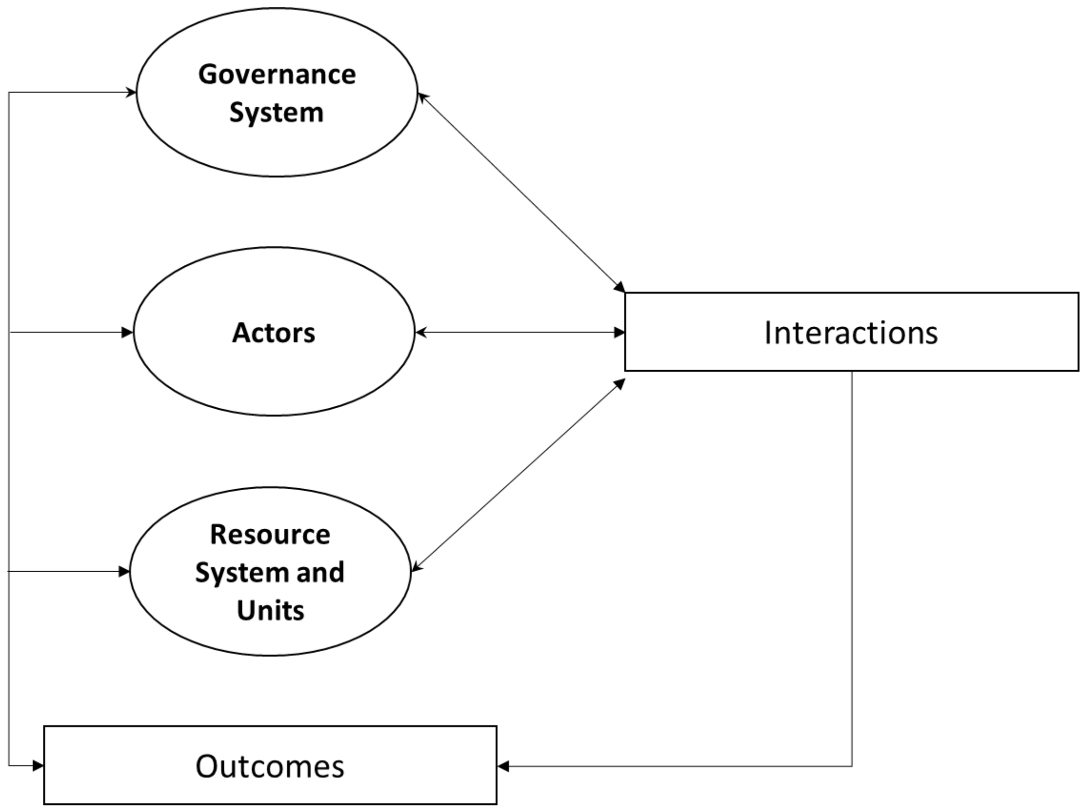

Figure 7.1 The framework used to structure data analysis. Adapted from Ostrom (2009).

According to this framework, the barriers to NFM uptake may exist within the various components of a SES as well as may emerge through interactions between the components. These are explained below.

7.3.1 Governance system

The governance system refers to both formal and informal institutions which guide activities to manage flood risk (Kaufmann and Weiring, 2017). This includes laws and regulations, debates, negotiations, public consultation, protest and further decision making actions (Ostrom, 2009; Mahon *et al*. 2017; Lebel *et al.* 2006). Governance does not have to derive only or primarily through the state, but can include many other actors, both governmental and non-governmental, which have governance over varying scales of NFM implementation (Lebel *et al*. 2006).

7.3.2 Actors

Actors are individuals who interact and create outcomes as part of the system (Ostrom, 2009). The term "actors" has been chosen as there may be individuals involved who are not necessarily users of the resource system, but who have an influence over the outcomes (McGinnis and Ostrom, 2014). This may include practitioners of FRM, NGO employees, members of the public, land managers and owners. All are part of the system and co-produce outcomes, yet some of these actors (such as NGOs or practitioners) may not be "users" of the biophysical or hydrological catchment in the same sense as land managers and the local community.

7.3.3 Resource systems and resource units

The term resource system is defined as the biophysical parts of the SES (Ostrom, 2009). Within NFM this may include the hydrological catchment, its size and its biophysical characteristics such as soil type, geology or topography (Mahon *et al.* 2017). Resource units refers to the resources within the catchment (Ostrom, 2009). Within a NFM context this could be individual NFM interventions such as bunds, LWD dams or woodland. However, it could also refer to economic units such as crops or livestock (Mahon *et al.* 2017).

7.3.4 Interactions

Interactions within the system are complex and can cross all four subsets of the system in both negative and positive ways (Mahon *et al*. 2017; Ostrom, 2009). For example, a negative interaction between land managers and legislation can be conceptualised as between actors and the governance system. Interactions can also be between actors and the resource system such as a land manager planting woodland in an effort to reduce runoff and soil erosion.

7.3.5 Outcomes

The outcomes of the SES framework can be varied across all four sub-systems (Ostrom, 2009). In the context of this research they can be both positive and negative. For example, a positive outcome may be NFM implementation with a hydrological monitoring programme and sustainable maintenance regime. However, negative outcomes from this may be land loss to a land manager and subsequent economic loss (Holstead *et al.* 2015). There may also be outcomes beyond the aims of FRM as a result of NFM implementation. For example, the wider benefits of NFM such as sediment capture, habitat creation and pollution reduction are discussed within the literature (SEPA, 2016; Lane, 2017; Nicholson *et al*. 2012). Thus, within the context of integrated flood risk management and sustainable outcomes, it is increasingly important that a holistic approach to overview the outcomes of NFM implementation, both positive and negative, is taken.

7.4 Results and Discussion

Table 7.1 shows the themes and corresponding source counts identified from the interview transcripts, concerning various barriers to NFM. As a general trend, it was found that land managers cited more barriers within the actor category whilst practitioners cited barriers across all categories. This may be due to the land managers citing specific barriers to themselves which would fall within the actor category.

Ecological factors, which are part of the SES framework, were not widely identified by interviewees as barriers. Although the study applies the SES framework on a conceptual level, the data collected focused more on the social aspects of the SES framework.

Table 7.1 Barriers to natural flood management identified during interviews, with source counts by sector (Green indicates low source count, red indicates high source count).

Category	Theme	NGO	Statutory	Academic	Consultancy	Local Government	Land Managers	Total Source citation count
Governance system	Lack of scientific evidence	5	7	2	2	1	1	18
	Lack of governance	5	7	1	2	1	2	18
	Lack of funding	5	6	2	2	1	0	16
	Policy challenges	4	7	2	1	1	0	15
	Transboundary catchment challenges	3	4	1	1	0	0	9
	Challenges over responsibility for NFM implementation	0	3	1	0	0	0	4
	Governance implications for land managers	1	0	0	0	0	0	1
Actors	Financial constraints for land managers	4	3	2	2	0	5	16
	Perceptions of NFM	4	5	2	2	1	2	16
	Actor lack of knowledge	2	3	2	1	0	4	12
	Land manager cultural challenges	1	2	1	1	0	5	10
	Intangible benefits of NFM	2	3	1	0	1	0	7
	Catchment planning concerns	0	0	0	0	0	5	5
	Land managers want evidence that NFM works	1	1	1	0	0	1	4
	Impacts of previous floods	1	0	0	0	0	2	3
	Land manager does not have time	0	1	0	0	0	0	1
	Land manager given negative advice on NFM	0	0	1	0	0	0	1
	Practitioner flood fatigue	0	0	1	0	0	0	1
Resource system and units	Site restrictions for NFM opportunities	0	0	0	0	0	3	3
	Number of land managers in catchment causes challenges	0	0	0	1	0	0	1
	NFM demonstration sites not applicable	1	0	0	0	0	0	1
Interactions	Interactions with land managers	3	3	1	1	1	5	14
	Interactions between practitioners	3	5	1	1	1	1	12
	Interactions with the public	1	2	1	0	1	0	5
	Negative media representation of NFM	1	2	1	0	0	0	4

7.4.1 Governance system barriers

Only one land manager stated that they would require greater scientific evidence to uptake NFM measures, suggesting that social-economic factors are more significant to them. However, within the practitioner remit, the current lack of evidence has wide implications. Current UK FRM policy requires a cost-benefit ratio to be calculated, as well as the number of properties that will have a lower flood risk as a result of FRM:

"…if you can tap in and find that evidence to show that natural flood management could work and to realise these benefits then the funding is available, but it's that chicken and egg, you've got to find the evidence first…" – Practitioner 1.

Without evidence that NFM has a beneficial impact, schemes are not currently being implemented due to the inability to calculate the cost-benefit ratio. There is also a current lack of public understanding which may be leading to uncertainty of its use as a FRM measure (Bracken *et al*. 2016). When these two factors are combined, a lack of funding occurs and the NFM interventions are not implemented. Therefore, opportunities to produce evidence are missed; consequently a feedback loop is created (Figure 7.2).

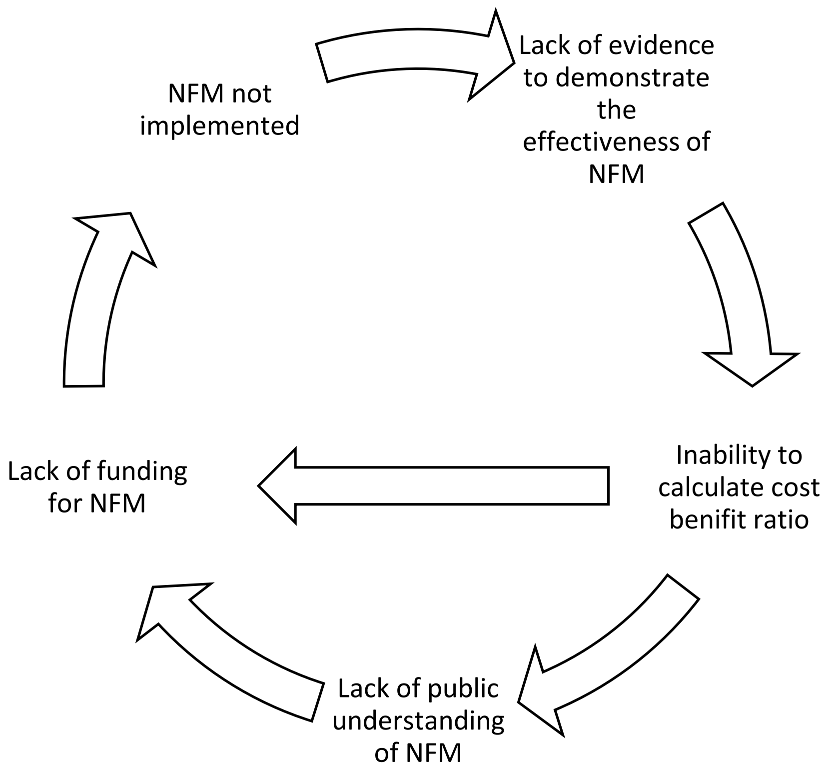

Figure 7.2 The feedback loop created by a lack of evidence and funding for natural flood management (Source: authors' own construction based on interview data).

Practitioners highlighted that the limited evidence for effectiveness of NFM has resulted in a lack of funding for capital works but, just as pressing, is the lack of funding for monitoring and maintenance of current projects. This has been discussed within previous literature (Barlow, Moore and Burgess-Gamble, 2014; Dadson *et al.* 2017; JBA Consulting, 2015) and links to another barrier identified within the governance system – FRM policy challenges. Practitioners stated that NFM benefits such as flood risk reduction and ecosystem services are complex to calculate and are often not tangible, therefore NFM is less likely to receive funding when compared to structural measures which allow for flood risk reduction to be calculated through standard hydrological and hydraulic modelling approaches (DEFRA, 2013).

This was also recognised within the community questionnaire data, as it was stated that there was "*not enough research and evidence that can help*". With another respondent stating that "*funding-as always, knowledge derived from research*" as a barrier, a need for funding to enable further research is highlighted.

The lack of funding for maintenance was cited by land managers as an issue, with practitioners stating that only capital costs for a scheme could be claimed. During a recent site visit by local land managers to an experimental NFM site within Southwell, this barrier was discussed as a significant barrier to them. This was also noted as a barrier by several practitioners, with acknowledgement that present NFM measures are not within the EA asset register, meaning that the structures cannot be included within maintenance plans.

"…if we were to request flood defence grant in aid or local levy funding for a scheme, we can only claim the capital costs towards doing the works…"- Practitioner 6.

"…at the moment those leaky dams do not find their way onto our [EA] asset register, and if they are not on our asset register, then there is no way we can plan for maintenance as part of our five year maintenance programme…"- Practitioner 5.

It has been argued within the literature that NFM is not represented within current English legislation (Howarth, 2017). This was raised by practitioners, suggesting that a lack of policy creates barriers to implementation though lack of consequent funding. However, it was argued by other practitioners that policies such as the Water Framework Directive (2000), the Flood and Water Management Act (2010) and the Flood Risk Management Act (2009) in Scotland do already support NFM implementation and a wider catchment based approach.

Issues over the governance of future maintenance such as *"identifying who is responsible for what in terms of maintenance"* was cited as potential barrier to the use of NFM by the community. Without a clear policy to govern the maintenance of NFM interventions, problems highlighted previously concerning the future effectiveness of interventions could be an issue. Therefore, it is crucial that policy is put in place to provide a clear governance structure for NFM measures.

In addition, a lack of guidance on how to maintain NFM interventions was mentioned by the at-risk community, with the lack of guidance on design of interventions also being cited. These barriers were not cited by practitioners, who would be the actors responsible for implementation, indicating that practitioners were not concerned about a lack of guidance for maintenance or deign. As more guidance has recently been published as an outcome of successful NFM projects such as Belford, Pickering and Holnicote, as well as the publication of the NFM Handbook by SEPA (2015) the Environment Agency NFM toolbox (2017) and the WWNP evidence base (2017), a lack of guidance as a barrier may have been overcome. Yet, as the local community recognise this as barrier, communication between practitioners and the public is required to show that design and maintenance considerations, which follow policy and guidance, have been made for NFM interventions which are to be installed within the upper catchment.

With the UK currently preparing to leave the European Union ("*Brexit*"), practitioners were both concerned and encouraged about the future of such legislation. On one hand, there was a concern that *Brexit* could lead to a change in funding for NFM interventions and the abolishment of legislation policed by the EU such as the WFD. On the other hand, it was argued that *Brexit* could allow for new funding such as agri-environment payments to land managers who install NFM measures.

Transboundary catchment challenges, between national or administrative boundaries, were mentioned as a potential barrier. The barriers within this theme were solely mentioned by practitioners, as no land manager interviewees had experience of working transboundary land. Challenges cited included data sharing across national boundaries, but also a lack of communication across administrative boundaries. As hydrological catchments do not adhere to national or administrative boundaries, communication needs to occur between stakeholders involved within the catchment rather than the political boundary:

"…recommendations of the Pitt review was to give the local flood authority a greater role in surface water management… but we were a little hesitant around it because our concern was that the political boundaries of county councils say, created effectively artificial barriers within that catchment system…"- Practitioner 9.

Challenges over the responsibility for NFM implementation were mentioned by practitioners as a further barrier to uptake. One practitioner from the statutory sector suggested that the EA is not the correct organisation to implement NFM, as projects require local ownership over longer periods of time. The interviewee mentioned that, as the EA is also a regulatory body, negative interactions with land managers may have occurred previously. This can create tension during the negotiation process and therefore links to barriers discussed within the interactions category.

Three practitioners stated that LLFAs should be implementing NFM, as they have local governance and responsibility over Ordinary Water Courses, which are often located in the upper catchment where NFM opportunities may have the greatest potential. One practitioner suggested that NGOs should be more involved during NFM implementation, as they have more flexibility with their objectives and can bring in external financial support.

Land managers on the other hand suggested that the IDB should be involved with NFM implementation projects as they were the organisation concerned with drainage. This highlights the need for multiple stakeholders to be involved within NFM projects in order for implementation to be successful.

7.4.2 Actor barriers

Lack of knowledge of NFM was mentioned as a barrier within several interviews. Four of the six land managers interviewed had not previously heard of the term natural flood management and failed to understand the aims of such interventions. Similarly, Holstead *et al.* (2014) found that 59% of farmers within their study knew nothing of NFM, which demonstrates the urgent need for dissemination of knowledge to the local level. Knowledge gaps cross between actors, such as the public or land managers not knowing what NFM is or how it aims to affect the hydrological regime of a watercourse (Holstead *et al*. 2014; Sniffer, 2011).

The lack of knowledge of practitioners was more complex, as these interviewees were selected for their understanding of what NFM was and what it aimed to achieve. FRM institutions in the UK contain a large proportion of employees from engineering backgrounds (Waylen *et al.* 2017). Therefore, due to unfamiliarity with new approaches, there was a reluctance to change towards softer engineered approaches, especially for employees who have a lack of experience of NFM methods. This demonstrates that a cultural shift is required by practitioners, to include NFM within FRM.

"We have never actually engaged in natural flood management in the form that you are looking at it now… retaining water in the upper parts of the catchment for short periods to reduce the flows downstream"- Practitioner 4.

A lack of knowledge of farming practices by FRM practitioners was mentioned by interviewees within the NGO sector. This creates challenges during stakeholder engagement activities, which can hinder NFM projects at an early stage (RPA, 2015). Therefore, this barrier is strongly linked to the interaction category within the SES framework, as a lack of knowledge of farming practices by practitioners may cause negative interactions to occur. For example, a negative interaction may be suggesting NFM be implemented in areas of the farm which are not suitable, or not understanding that losses of agricultural subsidies may ensue if productive land is altered. This suggests that, when approaching land managers to discuss potential NFM interventions, a representative who understands farming practices should be used.

As has been found in Chapter 6, the lack of knowledge of the at-risk community was found to have a negative effect on their attitudes towards NFM. The findings here support this argument and further demonstrate the urgent need for dissemination of knowledge to the public, but also to practitioners unfamiliar with NFM approaches. However, this will need to be targeted in different ways towards individual groups of stakeholder as knowledge gaps found within the Actors category as well as discussed in the literature vary between actors (Holstead *et al*. 2014; Sniffer, 2011). For example, the public or land managers may not know what NFM is or how it aims to affect the hydrological regime of a watercourse and so a basic understanding of this is needed. However, practitioners may have a lack of knowledge of farming or are unsure of how NFM can be combined with engineered FRM and so require different and more detailed information to expand on their knowledge.

Perceptions of NFM by various actors can also be a barrier to its uptake. Practitioners generally believed that the public perception of NFM was positive. However, nine of the practitioners interviewed highlighted that the public perception of NFM may be too positive and creates a reliance upon it as a FRM measure.

"…the other extreme is where you get communities who perhaps have got a natural flood management scheme and have got too much faith in it and believe it will protect them from flooding and stop flooding…" – Practitioner 11.

For this reason, expectation management is required when communicating the aims of NFM projects to the public. If expectations are not managed, communities may feel that NFM will protect them from flooding, which will lower overall resilience. This has also been cited within relevant literature (Holstead *et al.* 2015; Colley and Waylen, 2016; Nisbet *et al.* 2011).

The intangible benefits of NFM were also suggested as a possible barrier to uptake, because the flood risk benefits of NFM schemes are not immediately seen within downstream settlements. This causes a spatial disconnect between upper catchment management and the downstream community.

"…other situations have been where if you start doing works upstream where people can't actually physically see what you're doing- this doesn't give them a positive feel that flood risk is being managed…"- practitioner 1.

This suggests that further interaction between practitioners and the community is needed to explain what is being done in the upper reaches of the catchment in terms of NFM interventions, and how this will be of benefit to the downstream receptor.

Financial constraints for land managers were cited as a barrier by both groups of respondents. It was suggested that there is a lack of compensation available to land managers for installing NFM on their land. Related to this, land loss and a loss of income as a result of NFM implementation were also cited by land managers and practitioners as barriers to uptake.

"The financial side of it is a big issue and it's that you have to grapple with you know- government especially…"- Land manager 3.

As NFM can cause loss of productive land and consequently a loss of income to the farm business, land managers expressed opinions that such compensation was necessary if NFM was to be a viable intervention within their land. It is therefore essential for the success of NFM projects that payments are made accordingly for any financial costs which occur as a result of the intervention.

Land managers themselves were cited as a barrier to uptake within the questionnaire data. This included "*landowner reluctance/ lack of understanding* "alongside "*land owner perception + needs*". However, some respondents recognised barriers to land managers including land loss and a loss of income as a result of NFM intervention as well as the lack of funding for land manager to implement NFM. A loss of income and land loss have been found within this project as factors that reduce land manager acceptance; findings from the questionnaire data indicate that the local community recognise such challenges. As a result, there may be room for dialog between the local community and land manager to discuss how to compensate for a public good on private land.

Cultural challenges, such as a resistance to change as a result of ancestral influence on land managers, were cited as a barrier. The 'drainage culture' created as a result of historic incentives to maximise agricultural outputs through land drainage was also found to reinforce this.

"…a lot of our land had been low lying, my grandfather spent a lot of money on trying to drain his land to keep it in good condition…"- Land manager 2.

"Farmers have a long history, they manage the land, their father managed that land or their mother and they can trace back to their history very often to an area of land or a part of the country for a long time…and they will be very aware of their father or grandfather or whoever it is, talking about incentives from the government to drain the land harder…" Practitioner 9.

In the interviews, land managers expressed a reluctance to rewet land and were wanted to keep drainage free flowing. Practitioners generally did not cite this barrier, highlighting instead the need for greater interaction between land managers and practitioners. This barrier to land managers has been discussed previously by Holstead *et al*. (2014), but has not been found to be unrecognised by practitioners in previous literature.

Catchment planning concerns, such as increased development on floodplains or covering gardens with impermeable surfaces, were identified as an actor-based barrier. This was cited by five of the land managers, but not by practitioners. It was felt that, if NFM was to be used, better planning should take place within the downstream settlement to prevent development in at-risk areas. This may be due to land managers having specific opinions surrounding operation of the planning system within the local catchment where they farm. At present there is controversy regarding FRM and housing development within the town of Southwell, which may influence the attitudes of local land managers. If FRM is to be more sustainable nationally, such issues need to be addressed as part of wider, holistic catchment plans.

The impact of previous floods was mentioned as a barrier to land manager uptake. A specific barrier identified by one land manager was a lack of perceived control as a result of a previous flood event. Perceived control is defined as the belief that individuals can influence the environment and achieve desired outcomes (Wallston *et al*. 1987). The flooding event that Southwell experienced in 2013 was a high magnitude, low frequency extreme event which caused large scale runoff due to high intensity rainfall over a short duration of time (Suri and Page, 2014). Due to that extreme event, the land manager felt that NFM would be ineffective in reducing flood risk downstream. As a result NFM measures were not being considered as a viable FRM option. This barrier links the actor and governance categories, with a greater evidence base required to demonstrate the benefits of NFM is required to overcome this.

There were some barriers identified within the Actor category which were considered as niche barriers. For example, one practitioner suggested that practitioners may suffer from "flood fatigue".

"…the flood fatigue is set in and they think oh god no, not more controversy we've had enough of that and they go for the comfort zone rather than engaging…"- Practitioner 12.

It was felt by the practitioner that some FRM practitioners may not want to cause controversy and so may be reluctant to implement NFM as a result. This may be linked to the attitudes of the at-risk community if they are found to be unfavourable towards NFM. However, no further information was discussed regarding this barrier.

Another practitioner suggested that some land managers may have a reluctance to participate based on previous advice. For example, this could be negative advice given by a land agent which caused the land manager to become unfavourable towards NFM. Again, further elaboration was not given but highlights the importance of positive interactions if actors are to be favourable towards NFM.

A barrier identified by a practitioner was that some land managers may not have time to be involved within NFM projects due to the running of the farm business. This was not cited by land managers interviewed within this study and so was considered to be a niche barrier.

At risk community perceptions and "natural inertia- people generally assume flooding events are rare and unlikely to affect them" were cited as a barrier by the at-risk community. Respondents felt that NFM can be seen by the public as a "*do nothing approach*". It has been mentioned previously that public mistrust can be a potential barrier to uptake (Barlow, Moore, and Burgess-gamble, 2014), which was also cited as a potential barrier by questionnaire respondents within this research.

7.4.3 Barriers within the resource system

Few barriers cited by interviewees fell within the 'resource system and units' category. One land manager mentioned that catchment biophysical factors such as topography or the location of footpaths can create barriers to uptake, as they limit the spatial opportunities for interventions:

"on our property there is a footpath right next to the natural flood defence so that will impact on it as well"- Land manager 6.

Interestingly, such barriers were only cited by land managers, not by practitioners, which may be due to the more specific knowledge that land managers have of their land and catchment. This highlights the need for practitioners to draw upon local knowledge as a positive interaction to locate opportunities for NFM interventions.

Practitioners on the other hand cited barriers such as lowland farmed catchments not being applicable to upland NFM measures which have been installed as demonstration sites.

"…if you take Pickering for example it's a lot of forestry and the bit that isn't forestry isn't typical lowland farming as we see on the edge of the Yorkshire moors and some of the Northumberland…so we can't really draw a straight comparison between those sites…"- practitioner 3.

Although the evidence is anecdotal, current literature suggests that demonstration sites can improve the understanding and therefore the potential uptake of NFM by land managers (Holstead, Colley and Waylen, 2016; SNIFFER, 2011; Wilkinson, Quinn and Welton, 2008). Without demonstration sites which are comparable to those which are planned for NFM intervention, a barrier is presented as such knowledge sharing opportunities become limited due to other constraints.

Additionally, it was stated by practitioners that the number of land managers within the catchment can be a barrier as this can create communication difficulties between practitioners and land managers.

"putting features on land that's owned by hundreds of land owners and getting towards them in an effective way is going to be an interesting challenge I'm sure" Practitioner 16.

NFM requires multiple interventions across varying areas of the catchment, many of which will cross ownership boundaries. Resources can become stretched due to the effort that needs to be made to contact and engage with all of the land managers concerned. If NFM is to be installed in a holistic way which will have a significant impact on flood risk, a large number of NFM interventions will be needed meaning a greater number of land managers. Therefore, this barrier has significant importance if catchment wide NFM aims are to be met.

From the questionnaire data, respondents suggested that site restrictions are a barrier to NFM uptake from the community's point of view. From within the sample, housing development and agriculture were cited as such restrictions which are conflicting land uses to NFM. This links to the catchment planning concerns discussed in the actor's category. It was stated that in the case of tree planting, the lack of land available due to housing development was a barrier. As floodplain development occurs, there are less spatial opportunities for NFM interventions such as storage areas, tree planting or bunds.

7.4.4 Interactions

Practitioners suggested that negative interactions between different organisations posed a barrier to NFM uptake. This was mentioned by all sampled sectors of FRM. There is currently a structure for FRM within the UK which delegates responsibilities to multiple organisations including the EA, LLFA, water companies and Internal Drainage Boards (IDB).

It was suggested by the interviewees that organisations involved within a NFM scheme may have opposing views or different agendas for what they aim to achieve. It was also stated that the timescales for organisations may not align and this must be taken into consideration during partnership working. Thus, the governance system is creating barriers which apply to the 'interaction' category within the SES framework. Specifically, it was mentioned by interviewees that conflicts could occur between other FRM authorities and the IDB, as a result of such governance structures. Other FRM authorities seeking to implement NFM may wish to hold water on the land or to block existing ditches, thus creating a potential conflict of interests between organisations. Some of the land managers interviewed here were familiar with decisions of an IDB and they suggested that, since the IDB has a greater contact with land managers, it would be the best organisation to oversee FRM issues in relevant areas. This demonstrates trust from the land managers towards the IDB and so it is imperative that the objectives of the IDB and other FRM organisations are aligned, if NFM is to be successfully implemented by collaborative working.

"…the Environment Agency's flood risk management team can be singly focused on that role for managing and reducing flood risk, the Inland Drainage Board, managing flood risk is only part of their remit and obviously they are very driven by land drainage…and of course local authorities have a multitude of other remits and objectives competing for their time and their resources as well as their flood risk management…"- Practitioner 5.

The barrier of negative interactions also applies within organisations where different responsibilities exist. It was suggested that the lack of communication within organisations is causing a barrier to NFM implementation:

"…you have the flood risk people for whatever reason might not talk to their consenting and biodiversity people and one may have a very strong opinion but may not actually choose to explore it with colleagues to see whether things can be resolved…"- Practitioner 16.

Such institutional barriers could be due to the lack of resources available to communicate internally or the lack of willingness to change (Waylen *et al.* 2017). However, positive interactions can benefit NFM intervention if carried out within the early stages of the project and so should be encouraged within FRM institutions.

Respondents discussed negative interactions with land managers as a current barrier to uptake. Three of the land managers interviewed expressed views that a current lack of advisory support is a barrier to NFM uptake. Three practitioners also cited this barrier. Interestingly, practitioners who mentioned this barrier were all from NGOs and may reflect the fact that this sector recognises the support needed for land managers. Therefore, relevant NGOs may be better placed to advise and support land managers. Additionally, it was suggested that the EA may not be the ideal organisation to approach land managers, as they are also a regulatory organisation and so relationships may be harder to form:

" …we are still a regulatory organisation, so with some landowners, there may have been issues with us on- you know, environmental issues or they've had or visits from environmental officers or that kind of thing… you wouldn't want any potential scheme damaged because they've already got a prejudice against the Environment Agency…"- Practitioner 1.

Two practitioners stated that there is a current lack of stakeholder engagement with land managers. Land managers also said that they had experienced negative interactions, linked to the governance system, which would be a barrier to them undertaking NFM. It is crucial for future projects that positive engagement is used as an interaction to support land managers who wish to install NFM. This also applies to practitioner interaction with the public. Barriers cited include negative experiences of authorities in the past, public hostility towards the EA and a lack of community engagement overall. One stated example of a negative experience for communities was expressed as being let down by the governance system in the past, such as when a FRM scheme was not being implemented locally. One practitioner highlighted that, following the winter 2015 floods, public hostility towards the EA rose due to the severity of flooding and the perceptions that the public held. Stakeholder engagement should be core to NFM projects and needs to include the local community at the earliest possible instance, if such conflict and hostility is to be overcome.

Finally, media representation of NFM was discussed by four practitioners as a potential barrier to NFM projects. This has not been reported previously within the literature. Media representation of organisations involved within FRM and NFM can cause hostility between them and the public. However, it was also suggested that media outputs can report NFM outcomes as overly positive, so that expectations of what NFM can achieve are not being managed in a suitable way.

Within the questionnaire data, respondents quoted that "*vested interests*" and "*governmental commercial vested interests"* were a potential barrier to NFM uptake. Although the definition of the interests is limited, the respondents suggest that stakeholder interests are a challenge to NFM implementation. This barrier has been suggested in studies by Waylen *et al.* (2017) and O Donnell *et al.* (2017), who found that competing objectives within and between organisations involved within NFM and BGI implementation, is a potential barrier to uptake. As this barrier has been citied within the questionnaire data, and so is recognised by the public, it is critical that all stakeholders are identified and involved within NFM projects, but also objectives of each organisation are considered.

A "*lack of community engagement*" was recognised as a barrier by respondents. Stakeholder engagement is widely thought of as a crucial process within FRM projects, as it can increase acceptance through awareness raising and education (Lavers and Charlesworth, 2016; Challies *et al.* 2016; Begg *et al.* 2017; Lane *et al,* 2011). This can have wider benefits through the use of local knowledge, which gives the local community a sense of ownership over the project, but can also add in observational data such as runoff paths and intervention location opportunities (Cornell, 2005; Lane *et al.* 2011). It is essential that local residents are involved from the first stages of a NFM project, and that practitioners are transparent at all consequent stages of progress if this barrier is to be overcome.

7.5 Application of the SES framework for the identification and assessment of barriers to uptake

NFM intervention fits within the SES framework as its implementation is a human action which has an impact on the biophysical variables of a catchment, which are both subsets of the SES framework (Mahon *et al*. 2017). The individual categories of the SES align with the barriers to NFM uptake identified within this research. For example, NFM implementation requires actors (both land managers and practitioners) to have a positive interaction, whilst being supported by the current governance system in terms of funding or policy, in order to have a positive outcome. If a barrier is identified within one of these categories, it may have a negative impact upon the outcomes, such as a lack of policy to govern maintenance, meaning that a land manager as an actor does not want NFM on their land, and so an outcome of NFM not being implemented. The SES framework allows for barriers to be discussed across multiple categories whilst considering the points of view of multiple actors.

However, another framework which could have been use for the research was set out by Mills *et al.* 2017. Within this framework, as shown in Figure 3.5, sustainable NFM is achieved through overlap between land manager willingness to adopt, ability to adopt and land manager engagement. Many of the barriers identified fall within these categories and so this framework could have been applied to the research. However, the complex barriers may not have been explored in such detail due the limited number of categories which exist within the framework.

The SES framework has allowed for barriers to uptake to be identified and assessed as part of a more holistic systems approach. This has identified overlaps and links that some barriers have between the SES components. It has also allowed for barriers to be identified which concern multiple groups of interviewees, in this case land managers and FRM practitioners. Previous research has not used such an approach to look at the barriers within the system as a whole.

7.6 Conclusion

This study has applied a Social-Ecological Systems (SES) approach to identify and analyse the barriers relating to the uptake and implementation of NFM in the UK. Unlike previous studies of NFM, which have focused on a single group or limited aspect of the barriers, the SES framework has allowed for the barriers to be identified in a more holistic manner, rather than in isolation.

The findings here suggest that the barriers to NFM uptake and implementation are complex and diverse. They include not only the biophysical characteristics of catchments, but also factors such as a lack scientific evidence of NFM effectiveness, a lack of governance over the maintenance of NFM projects, land managers' past experiences and cultural beliefs, negative media representation of NFM, and problematic interactions between stakeholders.

Several individual barriers have also been identified by other recent studies. Examples include the lack of scientific evidence to show the effectiveness of NFM (Milman *et al*. 2017; Dadson *et al*. 2017, Wingfield *et al*. 2019), the absence of an effective NFM governance (Holstead *et al*. 2015), lack of perceived control over flooding (Waylen *et al.* 2017) and cultural influences on land managers (Holstead *et al.* 2014). More importantly, however, the application of the SES framework has demonstrated that such barriers may exist at multiple levels and are inter-related. For example, the lack of empirical evidence regarding the effectiveness of NFM leads to difficulties in gaining access to funding for NFM which, in turn, limits the opportunities to gather evidence. It is therefore recommended that NFM projects should build monitoring programmes into their funding bids, to assess the impacts on flood risk and maintenance needs and to build the evidence base to guide future NFM implementation.

The application of the SES framework also shows that the barriers to NFM uptake go beyond a single stakeholder. For instance, in the UK, the responsibility for FRM lies with multiple organisations, and therefore, it is important for these stakeholders to interact effectively for successful implementation of NFM projects. However, as this study finds, the barriers identified by one stakeholder group (e.g. land managers) may not be recognised by another group (e.g. practitioners), which may act as a barrier to productive interactions between them. Practitioners, for instance, highlighted barriers mostly within the 'Governance System' and' Interactions' categories, whereas land managers mostly mentioned barriers within the 'Actors' category. Moreover, some barriers discussed by land managers were not mentioned by practitioners. This suggests that a 'shared understanding' of NFM barriers probably does not exist in the UK. It is important that such bottlenecks to effective stakeholder interactions are identified and this is where a systems- and multi-stakeholder-oriented framework, such as the SES framework used in this study, can be useful. If the current research had focused on the barriers to land managers in isolation, this crucial barrier to productive stakeholder interactions would not have been found.

Notwithstanding these valuable insights, this study is limited in its identification of the barriers to NFM uptake relating to the attributes of 'resource systems and units', i.e. the 'ecological' aspects of SES. The few barriers identified in this regard were: site restrictions, the number of land managers within a catchment (leading to difficulty in catchment-wide application) and demonstration sites not being perceived as widely applicable. Some respondents did mention biophysical aspects, but questioning stakeholders explicitly on the “naturalness” of NFM would give further insight into the ecological aspects of NFM and could identify the interactions between the social and ecological systems. Such research may give insight into further barriers to uptake and allow for new approaches to NFM implementation to emerge.

8 Overcoming the barriers to NFM uptake though land manager engagement

8.1 Chapter Introduction

This chapter aims to assess whether land manager exposure to NFM intervention, through a demonstration site visit, can increase knowledge, change attitudes and modify behaviour towards NFM. As previously mentioned in Chapter 7, the complexity of qualitative data requires a structured analytical approach, for this reason, the data collected during interviews has been coded into categories set out within the SES analytical framework (Ostrom, 2012). This means that their perceptions were analysed in relation to the outcomes, governance system, resource systems and units, and interactions. A key focus has been to investigate if their perceptions of NFM have changed pre- and post- visit to the NFM demonstration site.

Unlike chapter 7, where the outcome was already known to be a lack of NFM uptake, this chapter has outcomes as a result of the demonstration site visit which are discussed in detail. Methods to overcome barriers which were cited by land managers are also identified and assessed, as many are viable methods which could be used to overcome the challenges faced. Furthermore, barriers to uptake which remain after the site visit are discussed. Therefore, this chapter offers policy makers and FRM practitioners a valuable insight into the challenges faced by land managers during NFM implementation, but also potential ways to overcome them.

8.2 Methods

Land managers who took part in the first round of interviews were invited to site for a demonstration of the experimental scheme at the Nottingham Trent University's Brackenhurst Campus, Southwell. One land manager who was interviewed previously, was not willing to take part in this phase of the research. A presentation was given to land managers at the start of the site visit to explain the aims of NFM within the catchment but to also show considerations of NFM design. Land managers were then shown around the experimental NFM site to discuss the interventions installed.

After the event, interviews were conducted with the attendees (n=5). The interviews were semi-structured and guided by a topic list (Appendix H) which made it possible to assess the knowledge, attitudes and behaviour towards NFM of land managers within the catchment. The guide included topics mentioned in the pre intervention interviews (Appendix G), as this would allow for practical barriers to be discussed. The interview guide also allowed for new barriers identified from the site visit to be identified. Interviews were recorded and transcribed by the researcher. Data was then thematically coded using Nvivo and the SES analytical framework. Responses were then compared to pre-intervention interviews using a matrix query, to assess if stakeholder engagement with land managers through demonstration site visit can change knowledge, attitudes and behaviour towards NFM.

8.3 Results and discussion

Table 8.1 shows the themes and corresponding source counts identified from the post site visit interview transcripts. In total, 23 themes were identified, many of which contain sub-themes which are discussed below.

As in Chapter 7, ecological factors were not widely identified as barriers by land manager interviewees. Although the study applies the SES framework on a conceptual level, the data collected focused more on the social aspects of the SES framework.

Table 8.1 shows that outcomes were identified within the chapter. Whilst many of these are positive, some negative outcomes did occur. As was found in the previous chapter, the actor category was found to contain the most themes, which possibly reflects the personal attitudes of land managers. However, additional new barriers were found within the resource system and units category. This may be due to individual land manager reflection on how they could implement NFM on their land, and what the possible consequences could be for their landholding.

Although the actor category has been found to contain the greatest number of themes, the governance category has barriers within it which have been suggested in previous interviews, and by relevant literature. As such, barriers within this category have a significant importance to the future uptake of NFM projects in the UK.

Table 8.1 Land managers' perceptions of NFM pre and post site visit of an experimental NFM scheme (Green indicates low source count, red indicates high source count).

Category	Theme	Land manager pre demonstration site visit	Land manager post demonstration site visit
Outcomes	Improved knowledge of NFM	0	4
	Land manager favourable attitude towards NFM	0	4
	Site visit improved land manager attitude	0	2
	Land manager unfavourable attitude towards NFM	0	2
	land manager would like NFM on their land	0	2
	Land manager interest in scientific understanding	0	1
	Land manager would ask researcher for support	0	1
Governance system	Lack of governance	2	5
	Lack of funding	0	3
	Policy challenges	0	1
	Lack of scientific understanding	1	0
Actors	Financial constraints for land managers	5	5
	Actor lack of knowledge	4	3
	Design concerns of NFM by land manager	0	3
	Land manager cultural challenges	5	3
	Catchment planning concerns	5	2
	Impacts of previous floods	2	1
	Land manager wants tidy land scape	0	1
	Land manager wants evidence that NFM works	1	1
	Perceptions of NFM	2	0
Resource system and units	Pest species concerns	0	2
	Site restrictions for NFM opportunities	3	2
	Topography restrictions	0	1
	Soil type issues	0	1
Interactions	Interactions with land managers	5	3
	Interactions between practitioners	1	0

8.3.1 Outcomes

The outcomes category within this chapter contains themes which have been identified as a result of the site visit. For example, results in Table 8.1 show that four of the land managers indicated that their knowledge of NFM had improved since the previous interviews, as they were able to describe what NFM is and describe complex processes surrounding implementation. Of the four, two specifically stated that that site visit had increased their knowledge and understanding of NFM. Therefore, an outcome of the site visit, which included the dissemination of findings of hydrological research, is an increase in the knowledge of participating land managers. The remaining land manager demonstrated some knowledge increase, as specific NFM interventions could now be explained, but their explanation of the hydrological aims of NFM was still limited, as demonstrated in the quote:

"*What do I think natural flood management is- I'd imagine it is water running off land*"-Land manager 2.

The attitudes of three of the land managers had become more favourable towards NFM after the site visit, one land manager demonstrated mixed attitudes, and the other maintained an unfavourable attitude. During the pre-site visit interviews, two land managers indicated a favourable attitude towards NFM, yet a lack of knowledge by the other four meant that they did not have attitudes towards NFM because they did not know what NFM looks like in practice or aims to achieve.

"*…and just thinking back to the site visit, do you think that [site visit] changed your opinion of natural flood management since your last interview*?"- Interviewer

"*I think it would've done…I think it shows that there's a potential to do it without having to spend huge amounts of money…"*- land manager 3.

These findings suggest that the feedback loop discussed previously which is a barrier to NFM could be overcome as shown in figure 8.1. Due to the site visit, the land managers were now more favourable towards NFM and so NFM would be more likely to be installed within the catchment.

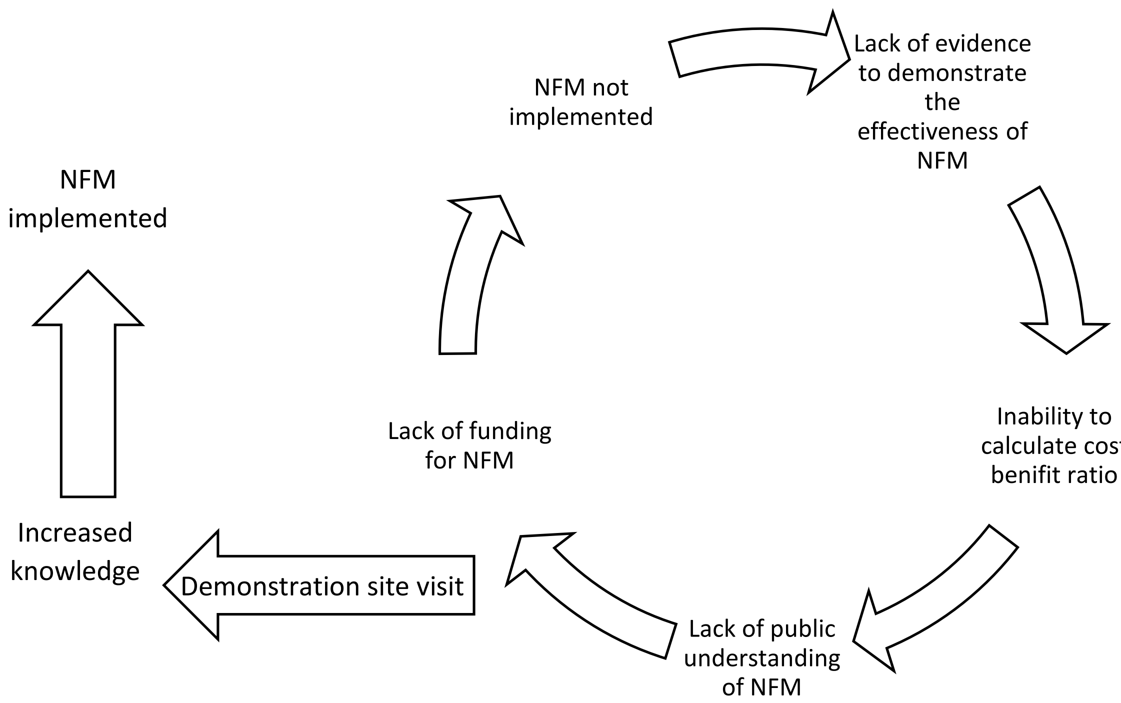

Figure 8.1 Breaking the feedback loop through land manger visit to a NFM demonstration site.

Previous studies have found that a lack of knowledge can reduce the ability for a farmer to uptake environmental actions (Mills *et al.* 2017). Within this study, findings have been made which suggest that improving knowledge of land managers though engagement may influence their attitudes towards it. Therefore, increasing land manager knowledge could help to overcome the barriers to NFM uptake.

Two land managers stated that the site visit had not changed their opinions towards natural flood management, and so the site visit had limited impact on their attitudes towards NFM intervention. One of these land managers also suggested that they would prefer engineered measures, as they felt flooding was a manmade issue and so demonstrated a negative attitude towards NFM during the interview. The land manager felt that NFM would not work with the practices of the farm and so expressed another negative attitude towards its implementation following the site visit.

"…*it's just not good enough for modern infrastructure, and so you've got to do balancing properly, and it's got to be under controlled conditions which are manageable*…"- Land manager 2.

"…*but its [NFM] not workable to my way of thinking in modern production methods or modern development methods…"*- Land manager 2.

Although the two land managers demonstrated negative attitudes, attitudes overall have been found to improve as a result of the site visit, as four land managers demonstrated a positive attitude towards NFM within their interview. This may be as a result of increasing land manager knowledge during the site visit. Islam, Barnes and Toma (2013) suggest that land manager attitudes are impacted by the information available and its communication to them. The demonstration site visit has the increased knowledge of some land managers though the provision of accessible information of NFM. In turn, this could help to overcome cultural barriers to uptake, as attitudes towards NFM become more positive.

During pre-site visits, land managers were not asked if they would install NFM on their land as they did not know what it was or aimed to achieve. However, during the post-site visit interviews, behaviour was found to have changed. Although one land manager was willing to install NFM during the pre-site visit interviews, that person now felt they had exhausted the opportunities on their land and so could not install more interventions. Two other land managers now indicated that they would like to install NFM or additional NFM interventions on their land in the future and so a change in behaviour has been observed.

"…there is one other site actually that I have pointed out, where we could introduce a flood management scheme…and the grassland there, it's an area at the bottom that could be made into a balancing pond or managed…"- Land manager 5.

Interviewer: Coming to site, do you think that you would be more or less likely to install natural flood management compared to your last interview?

"*Yes we would because it shows you what can be done and what you have and have not to spend"*- Land manager 3.

These results suggest that demonstration site visit could be a potential method to increase land managers' knowledge, and to influence their attitudes and behaviour towards NFM intervention. This will be crucial when upscaling NFM intervention to a wider catchment, as there needs to be consensus and connectivity between land managers if NFM is to have a significant impact on flood risk (Posthumus *et al*. 2008).

One land manager stated that they would approach the researcher for support if they were to install NFM in the future. This shows that some trust has been achieved as an outcome of the site visit as the land manager would ask the researcher for advice if they were to consider NFM on their land. As support for NFM land managers to install NFM interventions was found to be limited during pre-site visit interviews, site visits were found to be beneficial as they may increase the capacity of land managers to draw upon support and advice from FRM practitioners when needed. The lack of support for land managers installing NFM was discussed as a significant barrier by Holstead *et al*. (2015) in a study in Scotland. Therefore, site visits may offer a potential solution to overcome this barrier.

One land manager demonstrated an interest in the scientific experiment, which may be a potential method to help overcome barriers to uptake. It has been noted during talks with land managers, that some have personal weather stations within the farm business. It was found that these land managers had an interest in the scientific experiment which was ongoing within Southwell.

"…I'd love to be able to keep tabs on that [water levels] really, one way or the other… and it would be really interesting for us to be able to know what's happening there and have regular readings…"- Land manager 5.

"…*we have a weather system, we looked after it now and feed him [external contractor] with the data every month, so having the meteorology there, it's terribly interesting to measure the rainfall and see when the rainfall comes*"- Land manager 5.

This has also been discussed within the literature as Stoate *et al.* (2019) stated that involving land managers within participatory research is likely to enhance their level of engagement. Furthermore, local land manager knowledge could help inform models whilst increasing engagement and overall project acceptance as suggested by Hankin *et al.* (2016). Involving land managers within academic research could be a method to change attitudes and increase willingness to adopt. Data from personal weather stations could be drawn upon to not only increase the understanding of the catchment's hydrological processes, but to also give the land manager some ownership over the project which may in turn increase acceptance.

The findings of this study demonstrate that by engaging with land managers within the scientific experiment, in this case water level data collection, a positive outcome is achieved as the land manager is increasingly engaged with the project. For other NFM projects, knowledge exchange between FRM practitioners and land managers during data collection activities may increase favourability and change behaviour as has been previously discussed. Therefore, it is suggested that where applicable, land managers should be part of the scientific experiment and data gathering.

8.3.2 Governance system barriers

It was mentioned by all land managers in the post site visit interviews that the current lack of funding available for land managers to offset the potential economic losses as a result of NFM implementation was an issue. This barrier was also cited by land managers in the pre site visit interviews and so highlights that this remains a significant barrier to catchment wide uptake. Currently NFM is not represented within UK policy (Howarth, 2017), which has implications for uptake, as payments to offset losses during NFM intervention cannot be made within the current governance system. Therefore, a change in policy is needed if a public good, in this case FRM, is to be installed on private land.

It was discussed by land managers that some form of payment was required in order to overcome this barrier, this is a valid statement which is cited within the literature (Collentine and Futter, 2016; Milman *et al*. 2017; Howarth, 2017; Environment Agency, 2017). Preferred options were discussed to be compensation to land managers for land loss, or payments for outcomes. Specific outcomes which should be paid for were not mentioned, but one land manager suggested that a payment for results should be made in order to increase the efficiency of any compensatory payments. It was also suggested that payment could be made to land managers in order to maintain the interventions, which would than allow for an economic resource to be installed within the farm. Another land manager suggested that local residents could pay towards the costs of implementing NFM in the upper catchment.

"*If you want to do compensation, to my mind the only way to do compensation is to do it the way we was doing it after the war where if they wanted to boost something up the shoved the subsidy in, if* *they wanted to pull something back they pulled the subsidy out, and it made farmers change…"*-land manager 2.

"*Well if you can make the case that natural flood management reduces the risk of a flood in the town and you've also concluded that it needs maintenance or funding by someone other than the land manager, it seems to me that the natural place for it to be funded from is town council level and the impact should fall on the residents though a precept on the rates…*"- Land manager 6.

A lack of governance was mentioned as a barrier within the post site visit interviews. Within this theme, the governance over future maintenance were found to be a significant barrier to uptake. With no current FRM policy to address this issue (House of Commons Environmental Audit Committee, 2016), payment for land managers to maintain NFM interventions could be a viable option to overcome this barrier. This point is supported by McCarthy *et al.* (2018), who suggest that payments to land managers could be made for small amounts of storage and could include elements of maintenance built into them. In doing so, an economic resource is created for the land manager, whilst addressing maintenance concerns. With the House of Commons Environmental Audit Committee (2016) stating that the NFU have concerns over the lack of maintenance and the associated hindrance to uptake, this barrier needs addressing in an effective and sustainable manner.

"Well the antidote has got to be to maintain it yes, you've got to look after it…if it's going to be a contractual relationship between farming and government, if part of the contract is to provide a system and then there would be a reason to submit an invoice when it had been inspected and maintained annually, that's a reason for money changing hands from government to landowner, but for work done, so yes the landowners would maintain it…"- land manager 5.

Yet one land manager was against this idea, suggesting that maintenance would be better managed by a single authority in order to increase the efficiency, but also to make sure that maintenance is being carried out sufficiently. Therefore, due to the conflicting views, overcoming this barrier will be a complex process with more engagement with land managers and practitioner required.

"…I'm just thinking for example, the drainage pipes out of the bunds after an event, you know, someone's got to make sure that they are kept clear, should that be the land manager? Probably not no, because if you have twenty different people doing it, I think it's unlikely that all of them are going to do it properly…"- Land manager 1.

Another suggested method to maintain the interventions was to use volunteers. This could come from the local community and businesses within the at-risk community. As members of the community would see the interventions in practice within the upper catchment as a result, this may help to overcome the spatial disconnect between NFM intervention and flood receptor discussed by Collentine and Futter (2016). Moreover, this may help to overcome economic barriers through a reduction in costs for maintenance.

One land manager discussed that concerns over the future liability of NFM interventions was a barrier to them. Such liabilities were discussed in relation to future maintenance, but also the design and construction of individual NFM interventions. It was expressed that the land manager would like an organisation to take over the intervention so that future maintenance and liability would be given to an external organisation. With no current UK policy guiding maintenance or liability (Howarth, 2017), these barriers present a significant risk to the future uptake of NFM and are in need of addressing.

"*I think if I was going to do it [NFM] I would say right, there must be an organisation who would take it over and it would be up to them to look at it and design it and make it and generally be in charge of it*"- Land manager 1.

Policy challenges such as Brexit (Britain's exit from the European Union) were cited as having potential benefits for future funding for NFM from a land managers perspective. It was discussed that Brexit could allow for payments for services, which could include payments for NFM intervention and water retention on private land.

"…the quid pro quo could be post Brexit and all that when us farmers are not going to get any money from Brussels, how can they justify getting help from UK government should they need it, but there would be a case there for saying well this is an area payment and if you have got bunds on your land they you probably are justified in having a slightly higher rate because you are providing a service above growing the crop…"- land manager 3.

This was discussed previously within the interviews with practitioners yet was not mentioned in such detail by land managers during pre-site visit interviews. If NFM payments were incorporated into future farming policy after Brexit, it could help to overcome the economic barriers to NFM implementation within the governance system.

8.3.3 Actor barriers

Financial constraints for land managers, including a loss of income for the farm, was mentioned by all and managers during post site visit interviews. This indicates that concerns over the economic viability of the farm, if NFM is to be installed, is still a significant barrier to uptake.

"…at the end of the day my job is about earing a profit for the business, so anything I do has to return a profit and anything I do that doesn't return a profit hasn't got to have a drain on the business…" - Land manager 3.

Economic constraints to land managers been mentioned by all land managers pre and post site visit. As land managers will have the final say over NFM implementation on their land, there it is an urgent need for policy makers to put in place a solution to overcome this barrier. As previously discussed, policy is not in place to pay incentives to land managers, or to compensate them for financial losses to the farm business, which presents an actor based barrier caused by a governance barrier. Land managers also cited that the associated land loss which may result in a loss of income, was an issue for them. This further emphasises that if NFM is to be installed on private land, a payment to compensate for land loss is needed. This barrier has been reported within the literature with Holstead *et al.* (2014) finding that 53% of land managers within their study had not installed NFM as they felt their land was too valuable and Rouillard *et al*. (2015) suggesting that farm economics is the biggest barrier to catchment wide uptake. Additionally, following the UK Government's response to the House of Commons environment, food and rural affairs committee report on future flood prevention (2017), Howarth (2017) states it is recognised by the UK government that NFM presents a cost to upstream land managers and so compensation is required.

"*…the downside is that people will need paying, for people to do the things that you want to do, they're going to have to give up land or have land affected, so it's like everything in life, if it's not making money for somebody, you can be as optimistic as you like, but if you go broke for things for somebody else, there's no point…*"- Land manager 3.

Land managers raised design concerns of specific NFM features during the post site visit interviews. Some were in regards to the effective ongoing maintenance of the interventions.

"…I think I would have made the banks slightly less steep and more gentle so that you could put a flail mower over them or a mounted flail mover over them rather than a hedge cutter type, and also the safety about having a tractor roll over..."- Land manager 5.

"I think you would find erosion would take them [LWD dam] away or go around the side of it"- Land manager 1.

Whilst other land managers were more concerned about the impact of NFM on the land if designs were not thought out.

"…as long as it doesn't get to the situation where my land is getting water logged because I am doing it, because the last thing you want is where you get the situation you want is where the land becomes sad and unworkable…"- Land manager 3.

This highlights an important issue; NFM intervention has to work within the economic system of the farm business. In order to achieve this, interaction with the land manager at the design phase is required in order to install a NFM feature that will have a minimal impact on the farm, whilst providing effective FRM.

Cultural challenges such as a land manager suggesting NFM would change their landscape and make it look untidy was identified as a potential barrier to uptake. This barrier has also been discussed within the literature as Holstead *et al.* (2014) found that farmers felt NFM could make their land look untidy to others. However, this barrier may be overcome if NFM becomes used more frequently and so becomes a normal sight within an agricultural landscape. Furthermore, if NFM is seen to be "doing the right thing" by other land managers and the public, perceptions of NFM could change and this barrier could be overcome.

A further cultural barrier found during post site visit interviews was the drainage culture discussed in Chapter 7. This barrier was cited by fewer land managers compared to the pre site visit interviews (see Table 8.1), which may be as a result of the increase in knowledge of NFM discussed previously. However, some land managers still felt that drains should be kept clear in order to let water pass through as quickly as possible. Therefore, it has been identified that this attitude towards drainage has not changed for some land managers despite the NFM demonstration site visit.

"I like to think that my drains are taking the water away as quickly as they can so that I can work the land, so no I don't want water to hang around."- Land manager 1.

This is a correct statement in certain areas of the catchment where NFM interventions such as LWD dams could increase flood risk by blocking culverts for example. For this reason, NFM should be installed in watercourses well upstream of engineered structures. The drainage culture identified may be due to a lack of knowledge of the spatial application of NFM interventions within the catchment, and so more education is needed to clarify where interventions could be located and why those locations have been identified.

As previously mentioned within the outcomes category, the knowledge of land managers was found to have improved following the site visit. Although, one land manager still lacked knowledge of certain aspects of NFM.

"…do people want water to come down quickly to get rid of it or do they want it to come down slowly and have more days of flooding, I don't know…"- Land manager 1.

The above quote highlights that although this land manager could suggest what NFM interventions aimed to achieve individually, they lacked the awareness of the spatial application of interventions including the overall aim of holding water back within the upper catchment to reduce flood risk downstream. Therefore, for this land manager the site visit would require follow up engagement in order to improve deeper understanding of the aims of NFM and its preferred locations within the catchment to overcome the drainage culture barrier discussed.

Another land manager added to this, suggesting that there may still be a lack of awareness of NFM by other land managers.

"…people haven't considered it or haven't thought about it, it's not a question of being negative, it's more a question of awareness really…"- Land manager 5.

This supports the argument that land manager engagement, which improves knowledge and deeper understanding, is crucial for NFM project success when interventions are being sought on private land. The statement also suggests that more dissemination to land managers is required. Therefore, one site visit to a demonstration site may not be enough to increase the knowledge on land managers sufficiently enough to overcome barriers.

Further support for this argument was found within the interview data. Following the site demonstration, it was found that one of the land managers would still like to see more evidence before installing NFM on their land. The lack of evidence has been found to be a barrier to uptake during previous interviews and was cited by both land managers and practitioners. Current literature has highlighted this as an important barrier to uptake that needs addressing (Lane, 2017; Dadson *et al.* 2017; Burges-Gamble *et al*. 2017). Following the site visit, three land managers were found to be reluctant to install NFM without the evidence to show that it would have a FRM benefit. These land managers stated that they would like to see more scientific evidence to show the FRM benefits of NFM intervention.

"*I shouldn't have thought we've had enough experience yet have we… the Brackenhurst scheme needs to have a few years behind it and a few heavy real storms behind it which you can record and demonstrate what it's doing*"- land manager 2.

This quote emphasises that evidence to demonstrate the FRM benefits of NFM is being asked for. It was felt that although the site visit had allowed for preliminary results to be discussed, more data was needed in order to discuss the potential flood risk benefits in more detail. This may be due to the increase in knowledge observed, with land managers wanting a deeper understanding of the benefits to flood risk before installing NFM. Thus, NFM demonstration sites and other ongoing NFM projects should monitor impacts on catchment hydrology to allow for the dissemination of findings to other land managers.

Catchment planning concerns were raised during post site visit interviews. However, the focus of this barrier moved away from new housing developments which were stated within pre site visit interviews towards watercourse maintenance. It was expressed that rubbish was being thrown into the watercourses by downstream residents which could cause a blockage, so the lack of maintenance of watercourses downstream of the farmed land was considered an issue by land managers.

"*…they are still the same, if you don't clean them out, they don't work, Southwell had got a drain cleaning system, then all of a sudden the council made the cuts and we don't clean the gullies out any more- and when my neighbour says I'm pouring rubbish down the garden drain…*"- Land manager 2.

One land manager highlighted that during a previous flood event, significant damage was done to their property. As a result, it was stated that NFM interventions such as LWD introduction may not be preferred. Therefore, land manager previous flood experience still remains a barrier to uptake after site visit and has be an important consideration for practitioners when approaching land managers. Within Chapter 7, the previous flood experience of residents was found to have a negative impact upon respondent favourability towards NFM. When applied to land managers, this could still be the case as many land managers are also local residents. However, more research would be required to validate this argument.

"*…that big flood in 2013, it took away a whole lot of land, soil, bank [property name removed for anonymity]…and that was because there had been a blockage, of natural stuff, branches and rubbish and that sort of thing, and the water had gone around and eat the bank away, so it's not that simple to get it right*"- Land manager 1.

Within the actor category, it was discussed that there are possible methods to overcome the barriers cited. For example, it was suggested that some land managers were waiting to see if other land managers installed NFM on their own land. It has been discussed within the literature that community champions may help to overcome barriers to uptake (DEFRA, 2005). If a champion is identified for the farming community, this may increase uptake within the wider catchment.

Some land managers cited that they preferred an NGO or independent advisor to be involved within the NFM intervention process, as was indicated within the pre site visit interviews. It was felt that such organisations could give impartial advice and therefore support the land manager during the NFM projects, which is also a method supported by SEPA (2016). Some NGO's have a deeper knowledge of farming and the implications that NFM poses to the farm business and so may be better placed to negotiate NFM interventions with land managers. As it was previously found within practitioner interviews, interviewees (including those within the statutory body sector) suggested that the Environment Agency were not the appropriate organisation to approach land managers, with NGO's better placed to do so. This is an important consideration for future projects if cooperation with land managers is to be achieved and uptake maximised.

Finally, land managers expressed that they would like to help the local community and so were willing to consider NFM intervention as a result. Land managers felt that they are part of the wider community and should be engaging in activates, such as NFM, which benefit the community as a whole. This contradicts the study by Posthumus *et al.* (2008) who reported that farmers within their study felt that retaining water within their land was beyond good practice.

"… land managers in my opinion should be looking to help out really, and help their urban neighbours, if it's not costing them much just by managing their ground slightly different with these machines…"- Land manager 5.

However, the spatial disconnect between land managers in the upper catchment and downstream communities may create a barrier. If NFM intervention by land managers is not recognised by the at-risk community as beneficial for flood risk, as the community cannot see the interventions working within the at-risk area, tensions and conflict may arise. For example, some members of the local community may see upper catchment ditch blocking as negative due to safety concerns and so are against it. As a lack of knowledge has been found within Chapter 7 to have negative impacts upon community favourability, communication is needed with the at-risk community to explain how NFM within the upper catchment will benefit the at-risk community downstream, whilst giving credit to the upstream land managers who have installed NFM within their land.

8.3.4 Resource system and resource units

During the pre-site visit interviews, barriers cited within the resource system and units category were limited due to a lack of knowledge of NFM by land managers. Following the site visit which exposed land managers to NFM interventions, more barriers within this category were identified. This may be as a result of the site visit, as land managers had an opportunity to see the interventions in practice and therefore reflect on the implications to their land if such measures were installed. This is a similar finding to the report by RPA, RHDV and Allathan Associates (2015) which states that demonstration sites can help land managers to see how NFM interventions work and what the benefits may be.

A barrier identified during post site visit interviews was that pest species are a concern for land managers if they were to install NFM on their land. It was felt that NFM interventions could attract pest species to the farm, which would lower the value of the resource system. This is similar to the findings of Holstead *et al.* (2014) who found that farmers considered NFM high risk as it could bring pests and disease.

"*So if we have a dry summer and the water disappears, nettles, thistles, ragwort, and it will be a blooming nuisance*"- Land manager 1.

It was also mentioned that there could be site restrictions for NFM interventions such as NFM not working on smaller land holdings. This highlights that further education and dissemination of knowledge to land managers is needed. NFM is considered a mosaic of interventions over a catchment, this will involve multiple land managers and connective working (McCarthy *et al*. 2018). Although larger land holdings may be capable of installing a greater number of individual interventions, small landholdings also have place within this mosaic, especially if they are within areas that experience significant amounts of overland flow.

Additionally, barriers which apply to the geographical setting of the landholding were discussed. Topography was cited as a potential barrier as flat land may not be suitable for interventions which capture runoff due to the lack of runoff generation down the slope. Although this is correct, land management also has a part to play in runoff generation on land with a low gradient. For example, flat land is often drained for agricultural production. During rainfall events, such drains can exacerbate flooding in some areas if water quickly flows down the drains and into settlements where channel constrictions are encountered (Wheater and Evans, 2009). Therefore, methods such as LWD dams could be applied to reduce discharge, and land management intervention such as afforestation can be undertaken to increase soil infiltration, both of which can be installed on low gradient land.

One land manager felt the soil type may not be ideal for NFM to be effective. It was suggested that rocky areas may reduce the capacity for water storage if different runoff mechanisms are active during rainfall events when compared to their land.

"…I suppose one of the problems is the soil type, because if it's a rocky place it's going to be quite difficult to deal with anything…"- Land manager 3.

Whilst soil properties are an important consideration to make when selecting NFM interventions, there are interventions that can hold water within the upper catchment despite the soil type. For example, in clay dominated catchments, a focus towards overland flow attenuation is made due to the impermeability of the soils and resulting generation of overland flow. Whilst in catchments with sandy soils, a focus may be more towards in stream interventions to reduce erosion and discharge during events, or soakaway areas that hold water for a short period of time and can drain freely through the permeable soils (Avery, 2012). This suggests that although a valid point has been made, it is still important to educate land managers on the different types of intervention that can be applied on land with regards to the soil type. As the land managers interviewed farm within a clay soil catchment, and have visited a NFM scheme in the same catchment, this barrier may not be as significant in this case, but it is important to consider the soil type present within the targeted landholding, and make sure it aligns with interventions demonstrated during the planned site visit.

To overcome barriers within the resource system, a number of possible methods were suggested. Similar to the identification of barriers within this category, such discussion was not made during pre-site visit interviews, this further give evidence that the site visit has allowed for land managers to identify possible benefits that NFM could have on their farm to improve the resource system.

It was discussed that land managers were more willing to install NFM on their land if it had no negative impact on resource system. This is applicable to areas of waste land or grazing land, as the land is not taken out of production unlike if NFM were to be installed within arable fields. Wet land is often considered as bad or waste land for farming but offers a good opportunity for NFM as it often lies within runoff flow paths. Therefore, this land use trade off should be used when identifying NFM opportunities within farmland, as it creates less impacts on the land manager 's resource system. This finding is similar to that of Holstead *et al.* (2014) who found that land managers within their study were more willing to install NFM on wet, unproductive areas of land. Likewise, Rouillard *et al.* (2015) mention that land managers were much more willing to give up unproductive land.

"…we had a field which is only grazing and interrupting it for a season or two wasn't going to create and real trouble and might well create some advantage so I'm happy to cooperate with a plan to see if it would work…"-Land manager 5.

The impact on the resource system is an important consideration for practitioners installing NFM as interventions may have negative impacts on the farm. If negative impacts are a consequence, as discussed within the governance category, some form of compensation should be made if NFM is to be widely up taken by land managers.

Temporary NFM in winter was cited as a potential method of limiting the impact on the resource system. It was felt by one land manager that vegetation could be left to grow longer over the winter period and then be used for grazing in the summer. Whilst land management to increase infiltration and roughness is considered as a method to reduce runoff, within the Potwell Dyke catchment in Southwell intense rainfall during summer periods is a risk. Therefore, this suggested solution may not be effective. Yet, the point made is valid and may be of benefit during prolonged rainfall during the winter and so should not be disregarded.

Land managers also suggested that NFM could have positive impacts to improve the resource system. Some land managers suggested that NFM could provide a recreational or economic resource such as shooting ponds. If such resources are created as a by-product of NFM, uptake could be increased.

"…there's an opportunity for people to have ducks and stuff, you know, we don't need to just have a pond with nothing in it, it can be a wildlife thing as well as a flood management thing…"- Land manager 3.

All interviewed land managers mentioned that the benefits to wildlife were an important consideration to them. This links to promoting the wider benefits of NFM, which was discussed within pre site visit interviews as a method to increase land manager uptake. As the quote above highlights, water retention areas can be used for recreation purposes with higher aesthetic value but additional increases in habitat and biodiversity can be gained.

Additionally, it was suggested that NFM could be used to reduce pollution within watercourses. As the wider benefits of NFM have been identified as an important consideration after site visit, and is promoted within the literature (Holstead *et al,* 2014; Burgess-Gamble *et al*. 2017), it is important that such benefits are communicated to land managers effectively as a method to overcome the barriers to uptake.

"…there'll be some benefits and you can have those ponds where they've got reeds in them and stuff like that, they'll be benefits with that, they might be able to catch any pollution that might be coming through as well, you know, reed beds are very good a cleaning up streams, so you could have a benefit there…"- Land manager 3.

8.3.5 Interactions

A lack of interaction with land managers was still recognised as a barrier to uptake during the interviews. This includes the publication and communication of data to support NFM as a FRM measure. Without sufficient interaction, knowledge transfer opportunities will be lost and so uptake hindered.

"…until we spoke this morning and you gave the presentation, that hadn't been published or that hadn't been communicated…"- Land manager 6.

It has been discussed within this chapter that although land manager knowledge of NFM has increased after the site visit, education is still needed if a deeper understanding is to be achieved. This barrier has significant implications for uptake for wider projects and so effective interaction and communication is recommended.

Although positive interaction is needed, some land managers highlighted that they had experienced negative interactions with authority's concerned and so were reluctant to work with such organisations. This issue was discussed in pre-site visit interviews and backs up the point that an NGO would be better placed to deliver communication and provide an effective means of engagement between land managers and NFM projects.

To overcome barriers, land managers felt that more communication was needed to allow for successful knowledge transfer. It was expressed that this should be in simple terms in order for non-professionals to understand the points being made and the scientific evidence, which supports them. It was also felt that educating the younger generation could be a successful method to increase NFM uptake in the future, and so younger farmers should also be involved during knowledge transfer opportunities.

"*…there could be something that's in a college course, it doesn't need to be very long but it needs to be the importance of flood management and that as a farmer you're not just a farmer…"*- Land manager 3.

Starting education at this stage within a career could influence decisions made later within an individual's career. For this reason, educating farmers of all age groups and career points should be an important consideration if a holistic approach to FRM is to be taken and NFM to be installed in the future.

8.4 Conclusions

Without cooperation from land managers, catchment scale NFM which effectively targets runoff connectivity may not be possible. It is imperative that the barriers to uptake and possible methods to overcome them are considered. This study has found that the use of demonstration sites as a tool to increase land manager knowledge has been successful. Through knowledge increase, attitudes have improved and behaviour has been found to have changed, with more land managers now considering NFM intervention on their land. Although limitations exist to these findings, it has been specifically mentioned by interviewed land managers that the site visit achieved these outcomes. This provides evidence to support the use of NFM demonstration sites as a method to overcome barriers to NFM uptake.

Economic constraints to land managers was a barrier identified during both pre and post site visit interviews, highlighting that this barrier poses a significant risk to catchment wide uptake. Land managers discussed concern over the potential land loss and crop loss which could negatively impact the farm business. Currently, the lack of policy to compensate for economic losses is a pressing issue with policy lagging behind practice. Therefore, a solution is needed if catchment wide NFM is to be achieved.

Policy is also lacking when considering the maintenance of individual NFM interventions. Land managers were concerned about the future maintenance of interventions, and so are reluctant to install NFM on their land without a programme of maintenance in place. It was cited that maintenance could be undertaken by the land manager, and if a payment was in place for this service an economic resource could be installed within the land manager's resource system. This option offers a situation where the barrier to economic constraints could be overcome alongside the concerns over future maintenance and so should be considered by policy makers as a viable option to increase uptake.

It is recommended that during NFM intervention, practitioners choose sites and apply NFM methods which have as minimal an impact on the land manager's resource system as possible. It has been found that if unproductive land is used and disturbance kept to a minimum, land managers are more accepting of NFM interventions. This should be a consideration of practitioners during opportunity mapping as "quick wins" can often be installed on areas of land which have a lower value to the land manager's resource system.

Finally, it has been observed that greater interaction with land managers is still needed. The demonstration site visit has been an effective method to achieve this. However, it is felt that more interaction could be undertaken to involve land managers within the scientific experiment which may have been beneficial to overcoming the barriers to uptake. Such interaction should aim to disseminate knowledge to land managers so that they have a deeper understanding of the hydrological process of NFM and what it aims to achieve. It should also focus on the wider benefits of NFM to give more in depth knowledge of the benefits beyond FRM that can be achieved. In turn, this may improve attitudes and change behaviour towards NFM intervention, which could help to overcome land manager barriers to uptake.

9 Assessing the barriers to natural flood management implementation and uptake: Overall discussion

9.1 Chapter introduction

For interdisciplinary research to give a valuable contribution to knowledge, the insights from each aspect of the research need to be brought together in an overall discussion (Newell, 2001). This chapter discusses barriers to natural flood management uptake using the findings from each individual data chapter. The hydrological findings and the associated barriers are discussed first. This section focuses on the impact of overland flow storage within the field bunds. Following this, the social barriers which create a challenge to future NFM implementation are discussed.

9.2 Barriers resulting from hydrological findings

9.2.1 The impacts of natural flood management on the hydrograph

Within the literature, the lack of evidence to suggest that NFM can impact on the hydrograph and reduce flood risk is a significant barrier to NFM implementation (O' Donnell *et al.* 2017; Dadson *et al.* 2017). Data from this empirical study have been analysed with results suggesting that NFM can have an impact on the hydrograph. Results from Chapter 5 show that a change in relationship between the USD and LSD logger stage pre and post NFM has been found. Stage at the LSD logger during post NFM intervention events is lower than would be expected, when compared to the pre intervention relationship.

Reductions in peak flow during rainfall events at the Springfield Dumble subcatchment (slope) scale, as a result of bunds, have been identified for some events. During 30/12/17, where moderate intensity rainfall occurred over a short time duration, reductions in peak discharge at the LSD logger of 32.5-38.2% were calculated. During this event a significant change in hydrograph shape has was found, with discharge shifted from the peak to the falling limb, as has been theorized within the literature (Thomas and Nisbet, 2007). It has been stated within the literature that empirical evidence to indicate NFM has an impact of the hydrograph remains rare (Wilkinso*n* et *al.* 2019). Therefore, the findings of this research offer academics and practitioners valuable knowledge which has not been previously discussed.

However, there remains uncertainty of the impact of NFM during larger magnitude events. As change in the stage relationship between the USD and LSD loggers post NFM intervention was observed to be a curve, and the impacts on the hydrograph will diminish for larger magnitude events. Furthermore, for two events during which the largest peak stream discharges were recorded, the USD and LSD peak stage points fit closer to the pre intervention trend line. Results therefore suggest that during higher magnitude events, NFM may not be capable of reducing flood risk on its own. This is supported by relevant literature (Archer Bathurst and Newson 2016; Dadson *et al.* 2017; Burgess-Gamble *et al.* 2017; Wilkinson, Quinn and Welton, 2010a) and highlights the need for IFRM where a mixture of engineered FRM, NFM and community resilience is used.

9.2.2 The importance of available storage

For the two largest stream discharge events sampled, reductions in peak discharge at the LSD logger were observed. As the bunds did not overtop, and there remained storage space available within them, the bunds would be effective in storing water during greater magnitude rainfall events than those which have been recorded. The availability of storage during higher magnitude events is an important consideration for NFM practitioners, as interventions need to have available storage space during the peak discharge of the watercourse. This means that the outlet pipe must be of sufficient diameter to allow for storage of water during the peak of the event, and to allow for the intervention to drain down in time if another rainfall event was to occur shortly afterwards.

Detailed data has been collected which shows how individual bunds function in terms of water storage during rainfall events. This level of detail has not been reported previously in the literature. The data show that there remain instances where the bunds were not as efficient at storing water during the peak stream discharge as would be desirable. Also, each individual bund has been found to store different quantities of water during the same event, with the Common Mere bund usually being the most effective. While this may be due to the bund catchment size, spatial rainfall patterns could cause variation. Individual bund design is a vital aspect to consider so that storage is available during rainfall events and so that the bunds are not overtopped before the stream peak.

Temporal rainfall patterns could also have an impact on the efficiency of bunds. For high intensity, short duration rainfall events, when overland flow is generated, the bunds will be more efficient as they target this element of the hydrograph, as has been seen during the 30/12/17 event. However, for long duration rainfall events, where throughflow may produce a greater proportion of the hydrograph, the effectiveness of bunds may be reduced as water passes though the soil beneath them. This issue may be a barrier to implementation within catchments which feature sandy soils and so have higher infiltration rates. Within such catchments, NFM which consists of online and in channel features would be more efficient in reducing the peak of the hydrograph.

Bund design which does not consider the catchment characteristics or potential rainfall patterns presents another barrier to implementation. If overland flow generation ceases, yet throughflow has not yet peaked, the bunds may contribute additional discharge on the peak of the hydrograph. This has been found within this study during lower magnitude events. Whilst this has only been observed during lower magnitude events, which pose no risk of flooding, this evidence and the complexity of storage efficiency discussed, do demonstrate that NFM practitioners should carefully assess the characteristics of a catchment before installing NFM interventions. Within the literature, the theory of tributary peak synchronisation is discussed (Pattison and Lane, 2011), yet individual bunds discharging on the peak of hydrographs has not. Therefore, new evidence has been provided which will be a vital consideration for future NFM projects.

9.2.3 The complexity of upscaling to larger catchments

Whilst positive impacts on peak discharge have been demonstrated using bund analysis, when observed at the larger catchment scale, the impacts are much smaller than those seen at the slope scale. Evidence to suggest that larger catchment scale NFM will have a significant impact on flood risk remains elusive (Wilkinson *et al.* 2019). During all events, when storage at the slope scale has been upscaled to a larger catchment, the relative impact on peak discharge is lower.

However, the bunds have been shown to cause a reduction in peak discharge at the Potwell Dyke logger, even if it is a limited impact. It has been discussed that increasing the amount of storage within the catchment could have a greater impact on the peak of the hydrograph at this scale. When values were applied to represent 20 similar bunds within the catchment, a significant reduction in peak discharge was found. The findings from this calculation show a change in hydrograph shape, with discharge shifting from the rising limb and peak to the falling limb. This indicates that NFM could have positive impacts on the hydrograph during higher magnitude rainfall events at the catchment scale. However, more available storage, which is effective during the peak of the hydrograph is needed. This was also a finding of Quinn *et al.* (2013) whose modelling approaches concluded that 19,250m^3 of storage within the Belford catchment could provide a 30% reduction in flood peak for a 1 in 12 year event (Quinn *et al*. 2013).

Although evidence suggests that NFM at a larger catchment scale could be effective, as has been discussed, many barriers have been identified which need to be overcome for catchment wide NFM to be implemented. Without support from land managers, community acceptance or a governance system in which NFM fits, catchment wide NFM implementation will not be viable. Furthermore, as NFM is upscaled to larger catchments, multiple land managers will need to be involved which brings further complexities. In order to implement a sufficient amount of NFM on private land to have a meaningful impact of the hydrograph, the barriers to uptake from the point of view of land managers needs to be considered. This highlights the importance of an interdisciplinary study which goes beyond hydrological understanding and assesses the social system of which NFM intervention must fit into.

9.3 Social barriers to uptake

9.3.1 At-risk community attitudes towards natural flood management

At-risk community attitudes, specifically towards NFM, have not been previously discussed within the literature and so the findings from Chapter 6 contribute towards NFM literature. Although studies have researched community attitudes towards IFRM and Blue Green infrastructure (BGI) (Everett *et al.* 2018; Thorne *et al*. 2015), no study to date has specifically researched the attitudes toward NFM of at-risk communities and the factors which affect these. Thus, these findings add new knowledge to the field as they offer a valuable insight into community attitudes towards NFM. The attitudes of at-risk communities have been discussed as a vital consideration for FRM practitioners before and during NFM implementation if barriers to uptake are to be overcome.

Within this research, the at-risk community were found to show overwhelming support for NFM, with 76% of respondents agreeing or strongly agreeing that NFM is a viable option to reduce flood risk. Support for alternate FRM measures has also been found within other studies which assess attitudes towards IFRM (Bracken *et al.* 2016). It is possible that this is due to the paradigm shift in FRM from structural engineering to a holistic approach which considers wider environmental impacts (Hankin *et al.* 2016).

There are factors discussed which negatively impact on community attitudes towards NFM and therefore create barriers to uptake and implementation. For example, respondent knowledge of and attitude towards NFM was found to have a negative association. Results suggest that respondents who incorrectly answered the knowledge test within the questionnaire, were more likely to be unfavourable towards NFM in the case study area of Southwell. To overcome this barrier, greater community engagement is required in order to further educate residents. This needs to explain what NFM is and looks like, how it aims to reduce flood risk and its spatial application within the catchment. This in turn could help to improve community attitudes and therefore acceptance of NFM as a FRM measure. Moreover, discussion with residents regarding the spatial application of

NFM within a catchment, alongside an explanation that interventions will be within the upper reaches, could overcome the spatial disconnect discussed by Collentine and Futter (2016). This barrier is closely linked to the lack of evidence to demonstrate the impacts of NFM on flood risk. As discussed by practitioners within Chapter 7 and found within the literature, there is a current lack of evidence to show the impacts of NFM on the hydrograph, which in turn leads to other barriers such as a lack of funding (Environment Agency, 2012: Waylen *et al*. 2017; Wingfield *et al*. 2019). Without expansion of the evidence base and empirical findings to demonstrate the impacts of NFM on the hydrograph, this information cannot be effectively communicated to at-risk residents and so a further barrier is created. Therefore, it is vital that NFM projects monitor and collect data which can be used for dissemination if this barrier is to be overcome.

Practitioners of FRM have highlighted that community expectations need to be managed in order to overcome barriers to NFM implementation. As the results in Chapter 5 have shown, the impacts of NFM on stream discharge reduces as event magnitude increases. Literature also suggests that NFM is likely to impact on smaller magnitude events, with reductions in flood risk likely to be lower or non-existent during extreme events (Dason *et al.* 2017; Marshall *et al.* 2009; Hess *et al.* 2010). This point needs to be communicated to residents effectively, to manage their expectations of the impacts on flood risk.

Respondents' previous flood experience and attitude towards NFM were found to have a negative association (section 6.4). Results from the ordinal regression test showed that the respondents who had been previously flooded were significantly more likely to be unfavourable towards NFM. This barrier has been identified within the literature. For instance, Fitton, Moncaster and Gurtherie (2015) found that those at-risk of flooding focus on their quality of life and therefore would prefer structural measures which can be scientifically proven to reduce flood risk. Those not at-risk of flooding focus on the aesthetics of watercourses such as wildlife and habitat gains. Therefore, the previous experience of an at-risk community can be a barrier which creates a negative attitude towards NFM. Again, this finding highlights the need for effective dissemination which stresses the need for a mixture of NFM and structural engineering, but also highlights the wider benefits that NFM can achieve. This can be argued further as only a small percentage of respondents had experienced flooding in their home. It is conceivable that people living in at-risk properties could be more inclined to take part in the research. However, a large percentage of the respondents had not been previously flooded and their participation highlights their interest in FRM for the town, even though they may not necessarily be at risk from flooding.

Within the results, respondents were found to be mainly older and well educated, which reflects the data from the Office for National Statistics UK 2011 census (2016) for Southwell. As respondent demographics were not found to have significant associations with attitudes (section 6.4), the previous flood experiences of communities and their knowledge of NFM needs to be considered by practitioners who wish to install NFM upstream of an at-risk community. This key finding highlights an important point; that the local community do not hold views on NFM based on who they are, but on what they know. This means that change is possible and at-risk community attitudes towards NFM can be improved.

Stakeholder engagement with the local community could help to create a change in attitudes towards NFM. Mehring *et al*. (2018) found that 95% of their surveyed community wanted local residents to be involved within FRM decision making. Without stakeholder engagement, public understanding and acceptance of NFM may be reduced and NFM may not be implemented. Therefore, the barriers found within this section of the research highlights the importance of effective dissemination to at risk communities, which also manages expectations in light of empirical findings from Chapter 5.

9.3.2 Barriers to practitioners and land managers and the implications for wider uptake

Without consideration of the barriers to land managers and practitioners, NFM may not be a possibility at a catchment scale. The SES framework set out by Ostrom (2009) has allowed for complex and intertwined barriers to be considered across a wider range of stakeholders. Within this study, interviewees suggested that that lack of scientific evidence was a barrier to them. In consideration of this, the findings in Chapter 5 can be useful, as a lack of quantifiable evidence of the hydrological impacts of NFM presents a barrier to both land managers and practitioners. The lack of scientific evidence can lead to a lack of funding if cost benefit ratios are too low and mean that the project is economically unviable. Although more NFM projects are currently being funded at the time of writing, such as the £15m DEFRA catchment scale and community NFM projects (Defra, 2017), a lack of empirical evidence of the impacts on flood risk remains a barrier (Wilkinson *et al*. 2019). Therefore, this is in urgent need of consideration if NFM is to become a sustainable aspect of UK FRM.

Another barrier which needs addressing urgently is the current lack of governance of NFM projects. The lack of governance of NFM intervention maintenance for example was cited by all interviewees (section 7.4). At present, no policy exists to ensure that NFM features will be maintained by an individual or organisation in the UK. This provides a barrier, as land managers felt that they would not like NFM on their land if it was not going to be maintained properly in the future. The House of Commons Environmental Audit Committee (2016) have discussed this previously and highlighted that the National Farmers Union does understand the importance of NFM, but states that a lack of maintenance of NFM measures could cause prolonged flooding unnecessarily. This barrier has been highlighted by authors such as Holstead *et* al. (2014). If a land manager was willing to accept NFM on their land, policy needs to be in place to ensure that the interventions remain effective. As interventions such as bunds may become silted (Burgess-Gamble *et al*. 2017), a reduction in capacity may eventually cause them to overtop during high flow events, meaning that their storage capacity during the peak flow would be non-existent. In chapter 5, the findings have highlighted the importance of storage at the peak of the event and so ongoing maintenance to achieve this is vital. Also, measures such as LWD dams may become blocked after heavy rainfall due to debris movements and will rot over time meaning replacement is needed (Gurnell, England and Burgess-Gamble, 2018). If this is not carried out, NFM interventions will become less effective. As also discussed by England and Know (2015), underinvestment in maintenance could create further costs in the future. Therefore, governance over the maintenance of NFM interventions is needed if NFM is to fit within the current FRM system.

Land managers interviewed prior to the demonstration project mainly stated barriers which were applicable to the Actors category of the SES framework. This was due to them expressing specific concerns which they had if NFM interventions were to be installed on their landholding. At this stage of the experiment, 4 of the six land managers interviewed did not understand what NFM was or aimed to achieve. As discussed in Chapter 7, this could have a negative impact on attitudes towards NFM by land managers and so further dissemination and education is required to overcome this barrier.

All but one land manager stated that financial constraints of the farm were a current barrier for NFM uptake. This has also been discussed as a significant barrier to landowner uptake of NFM in Scotland, by Holstead *et al*. (2014). The barrier was acknowledged by practitioners within this research, and was also linked to the lack of governance barrier as there is no policy in place which pays land managers for any income lost as a result of NFM intervention or maintenance. This is a significant barrier and is in urgent need of addressing. At the time of writing this thesis, Brexit is creating uncertainty as to which payments will be available for land managers in the future. Some practitioners highlighted that new payments could be created to pay for ecological enhancements including NFM. Furthermore, DEFRA (2019) state that the intention of the government is to de-link payments, but that there is still much uncertainty over how it will relate to NFM and be implemented in practice post- Brexit.

Interviewees also expressed that negative interactions between stakeholders are a current barrier to uptake. Interaction between stakeholders is recognised as an important exercise during FRM projects (Thaler and Levin-Keitel, 2016; Tseng and Penning-Rowsell, 2012). These may be between land managers and the flood affected community as tensions will be high shortly after a flooding event, as occurred within Southwell after the 2013 event. Negative interactions may also occur between land managers and practitioners. This was expressed by both land managers and practitioners, acknowledging this as a potential barrier to NFM uptake. As the EA are a regulatory organisation, some practitioners stated that they were not the best organisation to approach land managers due to previous negative interactions. Therefore, organisations which understand FRM as well as the workings of the farm business, are better placed to negotiate NFM implementation.

This study also found that practitioners did not recognise some of the barriers which land managers face. Cultural barriers to land managers, such as keeping land drained, maintaining ditches and ancestral considerations, were generally not mentioned by practitioners as potential barriers, although these have been discussed within previous literature (Holstead *et al*. 2014). As land managers have the final say over implementation of NFM on their land, the cultural barriers are important and must be considered by practitioners. Without such considerations, negative interactions could occur which hinder NFM projects and so further barriers may be created.

Findings from this research can be useful for practitioners of FRM who aim to install NFM within a catchment. The results provide information on possible barriers to uptake and so could help to reduce negative interactions with land managers during negotiations. The data also can be used to inform FRM policy, which needs to recognise the governance constraints that NFM practitioners face within the current system. Catchment wide uptake will not be possible if these barriers are not overcome and sustainable policy put in place to ensure the continued effectiveness of interventions. As has been previously discussed throughout this research, NFM aims to install multiple features over a wide catchment area and will involve interaction with multiple land managers. Additionally, as found in Chapter 5, to have an impact on NFM at the wider catchment scale, a greater amount of storage beyond that of the slope scale is needed. If land manager uptake is not significant, this will not be achieved and so impacts on flood risk will be limited. Therefore, knowing about the barriers to the current uptake of land managers is vital for practitioners and needs to be considered within future UK FRM policy.

9.3.3 Overcoming the barriers to land manager uptake through a demonstration site visit

Although the barriers to land manager uptake have been discussed, specific methods to overcome these were not discussed in detail in the first round of interviews. One suggested method to increase uptake is to allow land managers to visit NFM demonstration site to increase their knowledge. It has been suggested that stakeholder engagement with landowners could achieve this (Challies *et al.* 2016; Posthumus *et al.* 2008; Environment Agency ,2017). More specifically it has been discussed that NFM demonstration site visits could help to overcome barriers to land manager uptake though the dissemination of knowledge (Wilkinson, Quinn and Welton, 2010b; Woodland Trust, 2013), yet no study to date has attempted to validate this theory. This part of the research discusses the impact of a demonstration site visit on land manager knowledge and attitudes whilst discussing the barriers which remain, and possible methods to overcome them.

Data from interviews following the site visit showed outcomes to be positive. Four land managers were found to have improved knowledge of NFM and could describe what NFM was and what it aimed to achieve. Two of the land managers specifically stated that the site visit had improved their knowledge. Some of the land managers interviewed also expressed improved attitudes towards NFM and that they would be willing to install NFM on their land. It was found that land managers were willing to help the at-risk community through NFM but barriers still remained which hindered this. From these outcomes, it could be concluded that the site visit had some success, with land managers specifically stating that the site visit had changed their attitudes towards NFM.

After the site visit, new barriers to uptake were identified. For example, design concerns such as limited mower access were highlighted by land managers. For NFM to be implemented in a wider catchment, it needs to have minimal negative impacts on the activities of the farm. It is crucial that land managers are engaged with the design process of an NFM project, if this barrier is to be overcome. The importance of NFM design has been discussed within Chapter 5, and so it is vital that design takes into account the implications for land managers as well as the need to effective storage during peak flows. Land managers have local knowledge which can help to inform possible locations of NFM features and so involving them within the design process may increase overall project success.

Maintenance of NFM features was still found to be a perceived barrier to NFM uptake following the site visit. This was mentioned by all land managers during the post site visit interviews and has been stressed as important throughout the discussion of this research. Governance over future maintenance is required, for future implementation to be successful. Some land managers suggested that the responsibility for maintenance could be given to the land manager, if a payment was made to carry out maintenance works. It was discussed by Mccarthy *et al.* (2018) that flood risk managers would like to pay land managers for activities which were seen to offer FRM. Paying land managers for maintenance of NFM features on their land could help to overcome multiple barriers. Firstly, it would help to alleviate the cited barrier of financial constraints of the farm by allowing for a payment to be made. Previous studies such as Holstead *et al.* (2014) have also found this to be a barrier to uptake. Therefore, paying land managers to maintain NFM features would create an economic resource for the farm. Meanwhile, it would allow for definitive governance over future maintenance which in turn overcomes governance barriers for both land managers and practitioners.

It was found during the post visit interviews that land managers wanted to see more empirical evidence which shows a positive impact of NFM on flood risk (Section 8.3.3). Studies such as Holstead *et al.* (2014) and Bracken *et al*. (2016) discussed this barrier to land manager uptake as they were unwilling to give up productive land for a method of FRM which is unproven and so may not be beneficial. A potential method to overcome this barrier may be to engage land managers with the scientific experiment. Land managers in the current study expressed an interest in the hydrological process of the catchment, with some owning personal weather stations. Involving land managers more directly within the experimental process may create a positive interaction which builds trust between practitioner and land manager. Moreover, it would provide data to support the current evidence base and so helps to overcome another significant barrier to uptake within the current governance system.

9.4 Future work

Evidence has been gathered to demonstrate the impacts of NFM at a slope scale. However, future work should concentrate on the impacts of NFM at larger catchment scales. It is currently unknown whether NFM is applicable at a larger scale, due to a gap within the literature (Burgess Gamble *et al.* 2017). Furthermore, empirical evidence is lacking due to the chaotic hydrological variables which make change difficult to detect (Pattison and Lane, 2012). Within this study, it has been confirmed that hydrological change is difficult to detect at a catchment scale. Therefore, future research should aim to measure the hydrological impacts of wider NFM at the larger catchment scale through observed data in order to fill the research gap. However, alternate methods beyond statistical testing may be needed and so the monitoring of individual NFM features will still be necessary.

Similarly, empirical evidence to suggest that NFM will reduce flood risk during higher magnitude events is still lacking. During this research, the events measured did not cause flooding in the town of Southwell. Future work should aim to capture data during events which have a higher return period in order to assess the impacts of upper catchment storage on flood risk. Therefore, research should be funded over a timescale in which more events can be recorded. This is especially important when assessing the impact of bund discharge on stream peak discharge, to assess at which magnitude of event the bunds would become overwhelmed.

Additional research is also required to assess the storage of individual bunds in more detail, to identify whether negative impacts on the hydrograph could occur. It has been discussed within this research that rainfall patterns, and catchment characteristics such as soil type, could create scenarios where the bunds discharge at the same time that stream peak discharge occurs. Future work should focus on this in more detail, to assess the possibility of unwanted consequences.

Within the use of the SES framework, the data collected did not reflect in detail on the ecological aspects of the SES. Some respondents did mention biophysical aspects such as the wider benefits that NFM can create but questioning stakeholders explicitly on the "naturalness" of NFM during future work would give further insight into the ecological aspects of NFM and could identify the interactions between the social and ecological systems. Such research may give insight into further barriers to uptake and allow for new approaches to NFM implementation to emerge.

9.5 Limitations of the research

9.5.1 Limitations to the hydrological study

There are several limitations to this research that need to be acknowledged. First, as shown in Table 5.7, the years following NFM intervention at Southwell have been drier than the annual average. This may cause a variation in antecedent conditions pre and post NFM, and could have caused variation in the runoff regime of the catchment, which was not a result of NFM intervention.

Inaccuracy in stream discharge calculation may occur during the development of rating curves, as it was not possible to use V notch weirs within the watercourses. Other methods set out within the literature were chosen (Shaw *et al*. 2011), but the additional uncertainty must be acknowledged.

There were limited amounts of data to assess hydrograph parameter changes using statistical analysis. Given the timescale of the experiment and the drier hydrological years which occurred after NFM intervention, the number of events used for analysis was limited. A longer timescale experiment would allow for more data to be collected. However, it is important that sufficient time is given to collect pre project data in order for comparisons to be made. Also, using this method to detect change in hydrograph parameters considers all NFM intervention installed, and so there is difficulty in identifying which individual interventions amount for which proportion of the detected change.

When calculating reductions in discharge as a result of water storage within bunds, the method assumes that ungauged bund catchments are functioning in the same way as the gauged Common Mere and 2nd Sunnydale bunds' catchment (Section 5.3.3). While the bunds all sit within the same subcatchment, variations in characteristics such as rainfall, preferential flow paths and land use could all impact upon bund storage. However, using this method to calculate storage of a gauged bund and comparing results to the observed data did show that the simulation follows the observed data pattern.

Using the outflow equation for bund discharge does not always give results which fit the observed discharge of the bund, as is shown in section 5.3.3. This may be due to blockages within the pipe as it was noted that straw could build up on the pipe after being washed down the field. It may also be due to further rainfall inputs, which enter the bund but are not great enough to turn the negative discharge into positive storage, but do increase the discharge slightly. To further validate the method used to predict ungauged bund storage, more simulated results from a greater number of events should be tested against observed storage within gauged bunds.

The complexity of hydrological processes and the changing state of the catchment provides another limitation of this study. As two rainfall events are never the same, due to differences in rainfall patterns, spatial distribution, and the antecedent catchment setting, it is difficult to detect change as a result of NFM. Additionally, the catchment land use (crop type) may not have remained constant during the timescale of this research and this may have an impact on results.

9.5.2 Limitations of the social research

There are limitations to the questionnaire which should also be considered. Firstly, the respondents may have participated based on their interest of future FRM intervention for the town of Southwell, meaning that the respondents had a greater interest in this study than the non-respondents. Therefore, responses may be biased towards those with an understanding of FRM and NFM. As the response rate was relatively low, the likelihood of bias of respondents is increased (Flowerdew, 2005).

The author of this research was asked to submit an article to the community resilience handbook about the NFM work being carried out within the Potwell Dyke catchment, in order to educate residents about the project. The questionnaire was distributed to the local community as an insert within the handbook. If this article was read before the questionnaire was completed, it exposes the respondent to educational material, which would have increased their knowledge of NFM.

During the interviews, as the land managers were selected by their location within the Potwell Dyke catchment, a limited number of land managers were included. This may have created some bias towards the current flood issues recognised within Southwell, such as having a vested interest in the current housing developments. However, the qualitative data gained from interviews with land managers gives a valuable insight into the current barriers to uptake that they perceive and face.

During the post site visit land manager interviews, outside factors may also have influenced knowledge, attitudes and behaviour of the sampled land managers, such as a growing public demand for NFM after the winter floods of 2015/16 (Hankin *et al.* 2016). Therefore, land managers may have been exposed to NFM through media outlets. As such, it cannot be out ruled that some attitudes may have changed as a result of factors beyond the demonstration site visit.

Furthermore, by the time of the second interviews, one land manager had installed NFM interventions on his land as a result of external funding outside of this research. Due to this, that land manager's favourability may have been changed as a result. However, two of the land managers specifically suggested that their knowledge had improved as a result of the site visit and one land manager suggested that the site visit had made them more likely to install NFM on their land so it can be concluded that using the experimental site as a tool to influence land manager behavioural intention to NFM uptake has been successful.

9.6 Progress in NFM implementation since the start of this project

Compared to the situation at the beginning of this research project (October 2015), NFM is becoming more widely used as a UK FRM intervention. It is therefore important to discuss the progress of NFM to date and which barriers have been overcome, alongside those which remain. When this project began, NFM was not widely used and only four key case studies were applicable. These have been discussed within the literature review (section 3.4). Following the 2015/16 floods, public desire for catchment wide measures increased and NFM was given a higher profile on the political agenda. Consequently, £15m of funding was allocated by DEFRA for catchment wide and community based NFM projects (DEFRA, 2017). This allocation of funding showed government support for NFM and begins to break the feedback loop of evidence needed to secure funding and funding needed to gather evidence. However, policy is lacking behind practice, with little governance over NFM, especially over its future maintenance needs.

Evidence to support the effectiveness of NFM has been discussed throughout this thesis as a significant barrier to NFM uptake and implementation. The Working with Natural Processes (WWNP) evidence base collated and summarised the current understanding of NFM and was published in 2017. This document assessed the understanding of NFM whilst offering a guide to practitioners who sought to install it in the future (Burgess-Gamble *et al*. 2017). This research project was one of the case studies included within the evidence base, yet at the time only the initial stages of the research were covered and so no hydrological findings were presented. The report concluded that there was some evidence to support the use of NFM in FRM, but that more was needed to fill in the research gaps identified. This includes evidence to support NFM at a catchment scale, and finding methods to measure change in hydrological systems where diffuse measures such as land use change are used.

Since the start of this research, gaps in the knowledge base have been recognised and some funding put in place to attempt to close them. For example, the newly funded DEFRA projects will expand the knowledge base in the future. Alongside this, academic organisations have responded to the need for hydrological understanding. Funding for research projects through the Natural Environment Research Council (NERC) initiative announced in 2017 for example shows a commitment to support the growth of the evidence base through catchment based research. Numerous conferences have also been held at which NFM has been discussed and promoted, at many of which this research has been presented (see list of dissemination activities from this project). Although barriers do remain, the factors discussed within this section highlight that FRM is shifting towards IFRM, where NFM plays a part in reducing flood risk for at-risk communities.

10Conclusions

This study aimed to assess the barriers to wider implementation of NFM and to contribute knowledge to the current limited evidence base. It has found that NFM intervention can reduce peak stream discharge and have a beneficial impact on the hydrograph. With empirical evidence to demonstrate impacts of NFM lacking (Wilkinson *et al*. 2019), this study offers findings which are based on observed data. Therefore, the results add to the current knowledge base and offer a unique and valuable insight into the possible impacts of NFM intervention on peak discharge.

Bunds within agricultural land have been shown to store water during rainfall events and release it after the hydrograph peak. This has caused a shift in discharge from the rising limb and peak of the hydrograph onto the falling limb. The bund storage hydrographs have given a valuable insight into how individual bunds function during rainfall events. It is concluded that consideration of the design of the bund is important, if water storage within NFM features is to be maximised during stream peak. If the bund is full at the moment of stream peak, or is discharging, the bunds will not be an effective FRM intervention and could even increase flood risk on rare occasions.

A change in the relationship between the peak stage at the Upper Springfield Dumble (USD) and Lower Springfield Dumble (LSD) has been found when pre and post NFM intervention event hydrographs have been compared. This shows that for a given event, peak stage is now reduced at the downstream (LSD) logger when compared to what would be predicted using the USD peak stage and the pre intervention equation. Again, this provides further evidence that NFM has had a positive impact on peak discharge.

However, it has been found that the impact of NFM on peak discharge is limited, when larger magnitude events have been analysed. When analysing the impact of bund storage on the hydrograph, for example, percentage reductions in peak discharge have been found to decrease during higher magnitude events. This is also found when comparing the USD and LSD stage relationships, with larger magnitude events found to have a closer relationship with the pre intervention trendline, meaning that the impact on peak stage is less.

When upscaling from the subcatchment to the wider Potwell Dyke catchment, the impact on peak discharge as a result of NFM intervention has been found to reduce. As this experiment focuses mostly on a small/slope scale, the results show a limited impact on the Potwell Dyke hydrograph during sampled events. However, as reductions in peak discharge as a result of bunds have mainly been positive, the findings indicate that more storage within the wider catchment could create a significant impact. When 20 bunds within the Potwell Dyke catchment were modelled for an event, a significant impact on peak discharge at Potwell Dyke (Park Lodge) was found. The finding highlights the need for a greater amount of storage within the wider catchment than has been implemented at the slope scale. To have a significant impact on the hydrograph at the catchment scale, it is likely that many stakeholders will need to be involved. Thus, in addition to the hydrological findings, NFM's place within the current social system has been assessed.

From the viewpoint of the at-risk community, attitudes towards NFM were found to be positive, with a majority of the respondents from the at-risk community supporting its use as a FRM intervention. However, two factors were found to predict negative attitudes: a lack of knowledge of NFM and respondents' previous experience of flooding. It is important that knowledge is increased to overcome this barrier, but at the same time it is crucial that expectations of the impacts of NFM on flood risk are managed. Given this research has found the impacts on the hydrograph decreased as catchment scale and event magnitude increased, these findings need to be communicated during community engagement activities. It is important that practitioners who wish to carry out community engagement acknowledge that those who have experienced flooding may be less favourable towards NFM. If this is not considered during engagement activities, negative interactions may occur which hinder NFM intervention.

When assessing the barriers to practitioners and land managers, many complex and intertwined barriers to NFM were identified. A barrier discussed by a majority of practitioners was the current lack of evidence to indicate that NFM would reduce flood risk, and so a cost benefit ratio cannot be calculated. This has been found to create a feedback loop whereby NFM is not implemented and evidence cannot be gathered. However, with the advances made within the NFM evidence base since the start of this study, the feedback loop may be beginning to break.

A lack of governance over NFM was found to be a significant barrier to uptake for both land managers and practitioners. The lack of governance over maintenance, for example, was mentioned by respondents as a significant barrier to uptake. At the time of writing, there is no policy in place to assign responsibility over the future maintenance of NFM interventions. Land managers were found to be unwilling to install NFM without an assurance in place which would ensure that the intervention would be maintained and kept efficient in the future. As the hydrological findings highlight the importance of storage efficiency, this barrier needs addressing urgently if NFM is to be a sustainable tool of future FRM.

It was found that some barriers to land managers were not always acknowledged by practitioners. Land managers indicated that cultural and ancestral influences can impact on their land drainage practices, so practitioners of FRM need to be sensitive to this if negative interactions are to be avoided. Furthermore, the organisation to approach land managers and discuss NFM needs to be carefully considered. It was suggested that the EA may not be best placed to do this, due to their regulatory powers over agricultural practices. As a result, those with closer knowledge of farming practices may be more suitable to discuss NFM on private land.

The lack of knowledge of land managers was found to be a barrier to uptake. A majority of the land managers interviewed in pre site visit interviews were not aware of what NFM was or what it aimed to achieve. This may influence attitudes in a negative way, as has also been found from the community questionnaire. For this reason, education is needed to demonstrate to land managers how NFM works and how it can be sustainably integrated into the farm.

Land manager site visit has been assessed as a potential method to overcome some of the barriers to uptake including a lack of knowledge of NFM. The site visit itself was found to improve land manager knowledge of NFM as well as their attitudes towards it. This may influence their behaviour as land managers were found to be more accepting of NFM on their land following the site visit. Therefore, demonstration site visits by land managers should be considered as an option to overcome some of the barriers to NFM uptake.

However, following the site visit, many barriers were found to remain and still caused a challenge to uptake. Again, the lack of governance was mentioned by land managers, specifically the lack of governance over maintenance. Land managers were found to be unwilling to install NFM on their land until this barrier was overcome. Paying land managers to maintain the interventions was a possible solution discussed. As financial constraints for land managers were also stated as a barrier during interviews, paying for maintenance would allow for an economic resource to be created within the farm. As NFM provides a public good, in this case FRM, on private land, a scheme which provides an income to compensate for land loss and crop loss, could help overcome several of the barriers identified within this research. Therefore, paying land managers to maintain NFM interventions should be considered as a possible way forward by policy makers, when assigning responsibility over the maintenance of NFM interventions. Such payments could be built into new agri-environment schemes following Brexit, but it is uncertain how this could be achieved.

The importance of NFM design was discussed by interviewed land managers following the site visit. Land managers were found to be more accepting of NFM if it had no negative impact on the resource system, in this instance their farm. For example, if the bunds drained freely and did not wet up the land, land managers felt that it would not have a negative impact on the farm and so were more accepting of implementation. It is vital that NFM designs are carefully considered to ensure that the intervention works with the farm business without creating negative consequences. For future projects, practitioners should consider involving land managers at the design stage of the project to help to overcome this barrier. As both stakeholders will have an understanding of how the intervention will function, this may lead to successful implementation. This highlights the importance of positive stakeholder engagement in NFM projects, if the barriers to uptake are to be overcome.

For future NFM projects, it is vital that the barriers to uptake and implementation to all stakeholders are considered. For that reason, this study has taken an interdisciplinary approach which has allowed for the analysis of barriers to cross between hydrological understanding and the role of NFM within the current social system. This has resulted in a deeper understanding of the complex barriers which exist to NFM uptake alongside a detailed analysis of them. The findings offer to practitioners data which can be used to inform future NFM projects and increase project success. The results can also be used to guide future policy, including the governance over NFM implementation and maintenance. It is vital that future FRM policy takes a holistic approach, which includes NFM within the upper catchment. Policy will need to establish a structured governance over NFM design, implementation and maintenance. As NFM needs to be installed over a wide catchment scale, many stakeholders with intertwined complex barriers will be involved. Therefore, if sustainable NFM is to be achieved, disciplinary boundaries will need to be crossed in order to consider such barriers and potential methods to overcome them.

10.1 Recommendations for future policy

- More empirical evidence is required to demonstrate the impacts of NFM on peak flows in order to quantify the economic benefits that it may create. To achieve this, future projects should have an element of monitoring built into the funding structure. Funding for monitoring should go beyond the initial phases of the project and should aim to gather longer term data.
- NFM will need to be implemented at a catchment scale in order to achieve a significant reduction in peak flows. This will mean a greater number of land managers will be involved. Therefore, future policy should work towards achieving this objective. Practitioners need to acknowledge the potential barriers to achieving cooperation of multiple land managers and should be mindful of them during engagement activities.
- NFM design should be informed by previous findings and lessons learned. This research has found that intervention design is key to maximise reductions in peak flow. Therefore, it is vital that policy continues to collate research outputs and lessons learned from NFM projects.

- Payments for land managers who are willing to install NFM on their land need to be implemented into agri-environment payments. This could be a payment for providing future maintenance of NFM interventions or a payment for the volume of water stored on the land during high flows. Without this policy in place, NFM uptake will remain low and catchment wide implementation will not be achieved.
- The future maintenance of NFM interventions needs to be built into policy to provide clear governance over maintenance responsibilities. This has been cited as a barrier multiple times within this research and so needs addressing within the current UK FRM governance structure.
- NFM demonstration sites should be available nationally to allow for dissemination activities to take place. The demonstration sites should be monitored long term to build the evidence base and support NFM as a FRM measure. This would increase land manager knowledge and uptake of NFM.
- A holistic approach to FRM is required for future NFM to be sustainable. Evidence from this study as well as previous literature suggests that no one FRM method implemented alone is a sustainable model to reduce flood risk. The holistic approach should include hard engineered FRM, NFM, community resilience building and emergency planning and should focus on activity at the catchment scale rather than at the point of the receptor.
- As barriers to NFM have been found across multiple stakeholders, including the at-risk community, land managers and practitioners, it is crucial that effective partnership working takes place when undertaking a NFM project. This will increase overall project success and help to leave a legacy for the at-risk community and land managers once practitioners move on from the site to focus on other projects.

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Appendix A: Sampled events' rainfall characteristics

Date	Event start (GMT)	Event end (GMT)	Event Duration (Hours/Mins)	Antecedent to peak (mm)	Rainfall Peak (GMT) Hour	Rainfall Peak (GMT) 15 min	Rainfall Peak (GMT) 5 min	Clock Hourly Rainfall (mm)	Rainfall Peak (mm) clock 15 mins	5 min rainfall peak (mm)	60 min rainfall (mm)	Total event rainfall (mm)
12/12/2015	12/12/2015 08:17	12/12/2015 19:25	11:08:00	10.6	16:00	18:30	12/12/2015 18:30	3.2	1.6	1.0	3.2	13.0
30/12/2015	30/12/2015 14:53	31/12/2015 06:11	15:18:02	2.6	30/12/2015 17:00: and 19:00	18:30 and 19:30	30/12/2015 17:06	1.6	0.6	0.4	2.0	8.8
03/01/2016	03/01/2016 11:05	03/01/2016 16:26	05:21:16		12:00	12:00, 12:30 and 13:30	not identified	2.0	0.6		2.0	6.8
07/01/2016	07/01/2016 03:35	07/01/2016 12:48	09:13:48	5.4	05:00	05:45	07/01/2016 05:49	2.8	0.6	0.6	3.6	13.4
05/02/2016	05/02/2016 21:44	06/02/2016 23:26	25:41	8.2 and 13.8	10:00 and 20:00	05/02/2016 23:45:00 06/02/16 06:45 and 20:15	06/02/2016 10:43:00 and 20:29	2.2	1.0	0.6 and 0.8	2.2	14.2
17/02/2016	17/02/2016 06:05	18/02/2016 00:16		1.6 and 7.8	10:00 and 18:00	08:30, 09:00, 10:30, 18:15		1.0	0.4		1.2	11.0
03/03/2016	03/03/2016 22:37	04/03/2016 04:31	05:53:24	5.0	02:00	21:45	04/03/2016 02:00	2.8	1.2	0.4	3.0	9.0
09/03/2016	09/03/2016 02:20	09/03/2016 10:07	07:47:36	11.8	06:00	03:30 06:16 06:30 06:45	09/03/2016 06:39	4.4	1.2	0.4 and 0.6	4.6	18.8
28/03/2016	28/03/2016 00:05	28/03/2016 16:00	15:55:00	11.2	01:00	01:15 and 06:46	28/03/2016 06:47	3.8	1.4	1.2	4.2	14.6

15/04/2016	15/04/2016 13:02	16/04/2016 05:03	16:01:00	4.0	19:00 and 21:00	19:30, 19:45, 20:45, 21:30	15/04/2016 19:38	2.6	0.6	0.4	1.8	12.0
14/06/2016	14/06/2016 17:19	14/06/2016 20:02	02:43:18	6.4	17:00	17:30	14/06/2016 17:46	9.4	4.0	2.0	11.4	18.8
29/06/2016	29/06/2016 08:42	29/06/2016 19:31	10:48:32	10.6	15:00	15:00	29/06/2016 14:55	5.4	4.2	2.0	9.0	18.2
21/11/2016	21/11/2016 04:54	21/11/2016 16:47	11:53:12	26.2	15:00	04:00 and 04:15	21/11/2016 16:12	7.4	2.8	1.4	10.4	30.6
06/02/2017	06/02/2017 17:43	07/02/2017 07:14	13:31:00	0.8	06/02/2017 19:00	Peak not identified	Peak not identified	1.4			5.2	1.8
27/09/2017	27/09/2017 18:10	28/09/2017 04:08	09:58:00	8.6	27/09/2017 22:00:00 28/09/17 00:00	28/09/2017 00:00	28/09/2017 00:03	1.8	1.0	0.4	2.0	12.4
25/12/2017	25/12/2017 19:15	26/12/2017 00:46	05:31:00	5.4	25/12/2017 21:00	25/12/2017 21:30	25/12/2017 21:40	3.0	1.0	0.6	3.2	7.8
26/12/2017	26/12/2017 19:56	27/12/2017 12:52			26/12/2017 22:00	26/12/17 22:00 and 22:45	not identified	1.2	0.4		1.2	10.2
30/12/2017	30/12/2017 01:19	30/12/2017 05:09	03:49:38	3.60	03:00	03:00 and 03:15	03:11	3.0	1.2	0.6	3.6	7.8
05/01/2018	05/01/2018 09:45	05/01/2018 14:59	05:14:10	4.20	13:00	13:15	not identified	2.8	1.0		3.0	7.0
09/03/2018	09/03/2018 17:54	10/03/2018 08:46	14:51:42	5.00	09/03/2018 22:00	09/03/2018 22:45 and 23:15	09/03/2018 23:15	1.6	0.6	0.4	2.0	8.8
11/03/2018	11/03/2018 19:01	12/03/2018 23:30	28:29:00	5.80	12/03/2018 13:00	12/03/2018 10:00 and 13:30	not identified	2.4	0.8		2.8	17.6
30/03/2018	30/03/2018 14:05	31/03/2018 15:49	25:44:00	3.60	30/03/2018 20:00	30/03/2018 20:00	not identified	2.8	1.0		3.6	15.2

31/03/2018	30/03/2018 14:05	31/03/2018 15:49	25:44:00	12.60	31/03/2018 13:00	31/03/2018 13:00	not identified	2.4	1.2		2.8	15.2
02/04/2018	01/04/2018 22:18	02/04/2018 13:03	14:45:00	8.80	02/04/2018 07:00	02/04/2018 07:15	not identified	2.2	0.8		2.6	15.4
03/04/2018	03/04/2018 13:19	04/04/2018 21:20	32:01:00	4.80	04/04/2018 13:00	04/04/2018 13:15	04/04/2018 13:22	2.2	2.2	1.4	2.4	7.6
10/04/2018	09/04/2018 15:55	10/04/2018 09:49	17:54:00	17.60	10/04/2018 05:00:00 and 06:00	10/04/2018 06:30:00 and 07:15	10/04/2018 07:16	2.0	1.0	0.6	3.2	18.6
12/04/2018	12/04/2018 22:08	13/04/2018 05:32	07:23:48	4.60	13/04/2018 04:00	13/04/2018 01:30:00, 04:45 and 04:30	13/04/2018 04:33	0.8	0.6	0.4	2.0	6.2
02/06/2018	02/06/2018 07:16	02/06/2018 11:26	04:09:54	6.80	02/06/2018 07:00	02/06/2018 07:30	02/06/2018 07:45	9.2	4.0	2.4	10.4	12.6

Appendix B: Sampled events' hydrograph parameters

Pre NFM intervention hydrograph parameters

Event	USD Time to peak (mins)	USD time to recede (mins)	USD event duration (mins)	USD peak (m)	USD peak Q (l/s)	USD lag time (mins)	LSD Time to peak (mins)	LSD time to recede (mins)	LSD event duration (mins)	LSD peak (m)	LSD peak Q (l/s)	LSD lag time (mins)
04/03/2016	125	590	715	0.18	19.8	80	175	1030	1205	0.145	41.21	154
09/03/2016	160	735	895	0.29	34.9	76	205	905	1110	0.262	181.70	126
28/03/2016	90	275	365	0.18	19.8	69	145	255	400	0.143	40.18	128
16/04/2016	190	605	795	0.13	13.5	253	205	550	755	0.101	23.59	292
28/04/2016	50	220	270	0.08	7.6	30	50	120	170	0.076	17.18	108
21/11/2016	180	495	675	0.368	46.3	21	280	255	535	0.335	458.54	31

Post NFM intervention hydrograph parameters

Event	USD Time to peak (mins)	USD time to recede (mins)	USD event duration (mins)	USD peak (m)	USD peak Q (l/s)	USD lag time (mins)	LSD Time to peak (mins)	LSD time to recede (mins)	LSD event duration (mins)	LSD peak (m)	LSD peak Q (l/s)	LSD lag time (mins)
27/09/2017	255	1115	1370	0.219	25.0	67.0	205	255	455	0.043	11.30	147
25/12/2017	80	1320	1400	0.306	37.2	90.0	70	755	825	0.128	33.22	154
26/12/2017	320	1510	1830	0.373	47.1	-	145	890	1035	0.144	40.69	-
30/12/2017	125	745	870	0.412	53.0	66.0	95	705	800	0.18	64.23	74
05/01/2018	185	2035	2220	0.376	47.5	100.0	120	980	1100	0.147	42.27	120
09/03/2018	180	2910	3090	0.332	41.0	54.0	75	385	460	0.084	19.01	91
11/03/2018	280	565	845	0.387	49.2	80.0	315	625	940	0.182	65.88	117
30/03/2018	115	-	-	0.37	46.6	76.0	60	660	720	0.226	115.10	105
01/04/2018	330	2715	3045	0.436	56.7	56.0	320	415	735	0.346	527.18	130
03/04/2018	275	615	890	0.329	40.6	269.0	345	630	975	0.113	27.46	303
09/04/2018	520	3360	3880	0.363	45.6	12.0	530	900	1430	0.313	346.91	55
12/04/2018	210	495	705	0.31	37.8	58.0	185	485	670	0.113	27.46	91
02/06/2018	45	1305	1350	0.262	31.0	20.0	40	690	730	0.104	24.50	64

Appendix C: Results using rainfall-runoff modelling to calculate ungauged bunds storage

Results from rainfall runoff modelling to calculate ungauged bund storage show that during the 2/4/18 event reduction in peak discharge were calculated at 30.4 -34.3 ls^{-1}(5.6 -6.3%) using data from the 2nd Sunnydale and Common Mere bund respectively (Figure C.1). During the 10/4/18 event reduction in peak discharge were calculated at 46.2 -47.1 ls^{-1} (12.1 -12.3%) using data from the 2nd Sunnydale and Common Mere bund respectively (Figure C.3). Whilst calculated reductions are comparable to the reduction in peak discharge results for each event shown in section 5.3.3, which used a catchment ratio to calculate ungauged bund storage, Figure C.2 shows that the Micklebarrow Springfield bund does not store water comparable to the pattern observed of storage in the two gauged bunds. This is also shown in Figure C.4 during the 10/4/18 event. This may be due to the method applying a set runoff coefficient which may in fact vary throughout the duration of an event. Another reason for the limited results is that when rainfall stops for a period within an event, the storage of bunds also stops. Within the field, this would not be the case due to a delay between rainfall falling to the ground and reaching the bund.

Furthermore, errors were found to occur during high intensity rainfall, where large spikes in storage were observed within the ungauged bund storage simulations which were not observed within gauged bunds. This again may be due runoff coefficients causing an over prediction of the actual overland flow. Due to these errors and a poor fit between gauged and ungauged data, the results from this method were not discussed within the thesis.

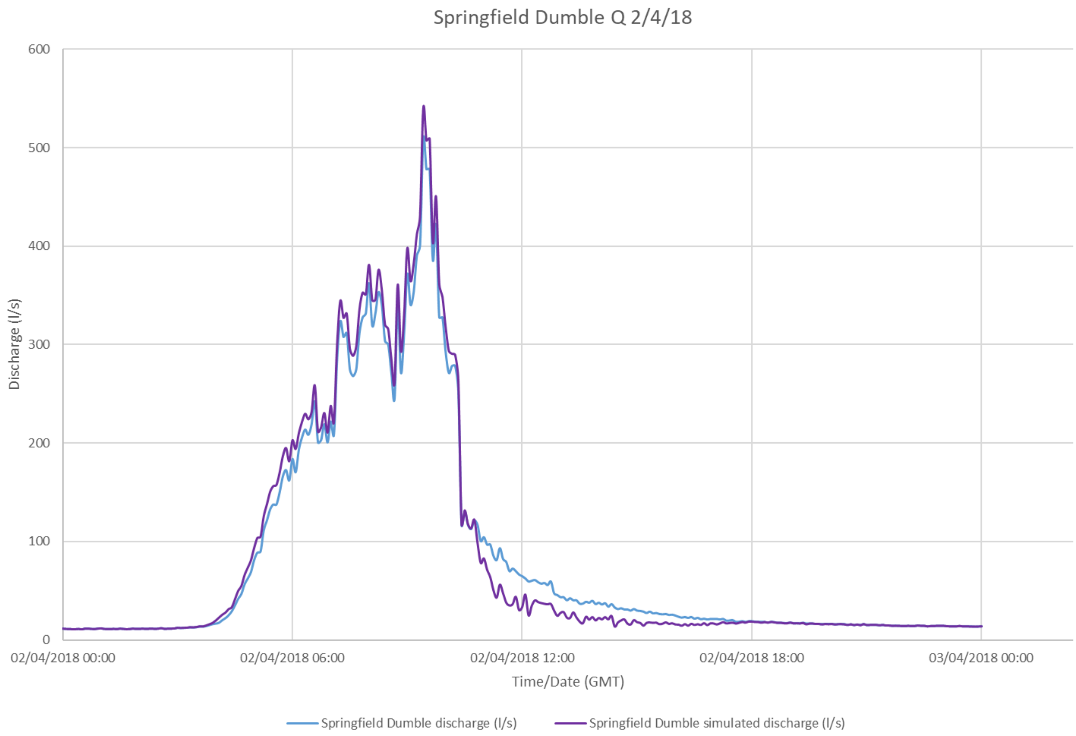

Figure C.0.1 Observed and simulated Springfield Dumble discharge 2/4/18 using 2nd Sunnydale bund data

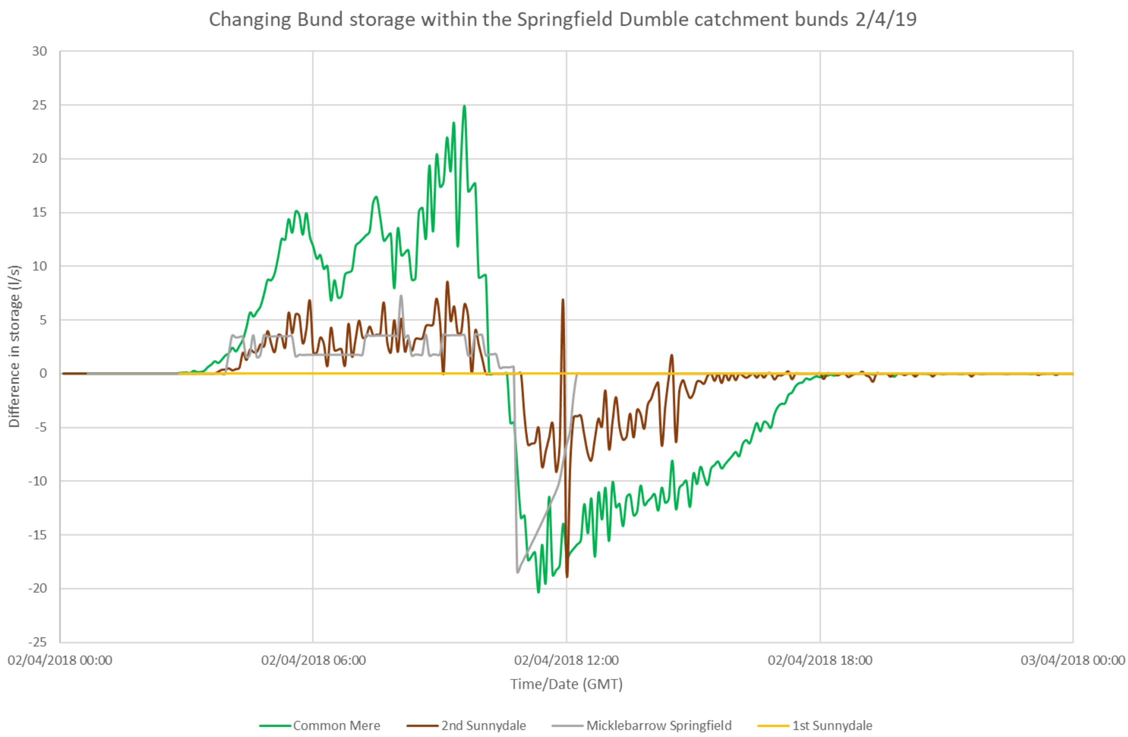

Figure C.0.2 Changing bund storage within the Springfield Dumble catchment bunds using 2nd Sunnydale bund data 2/4/18

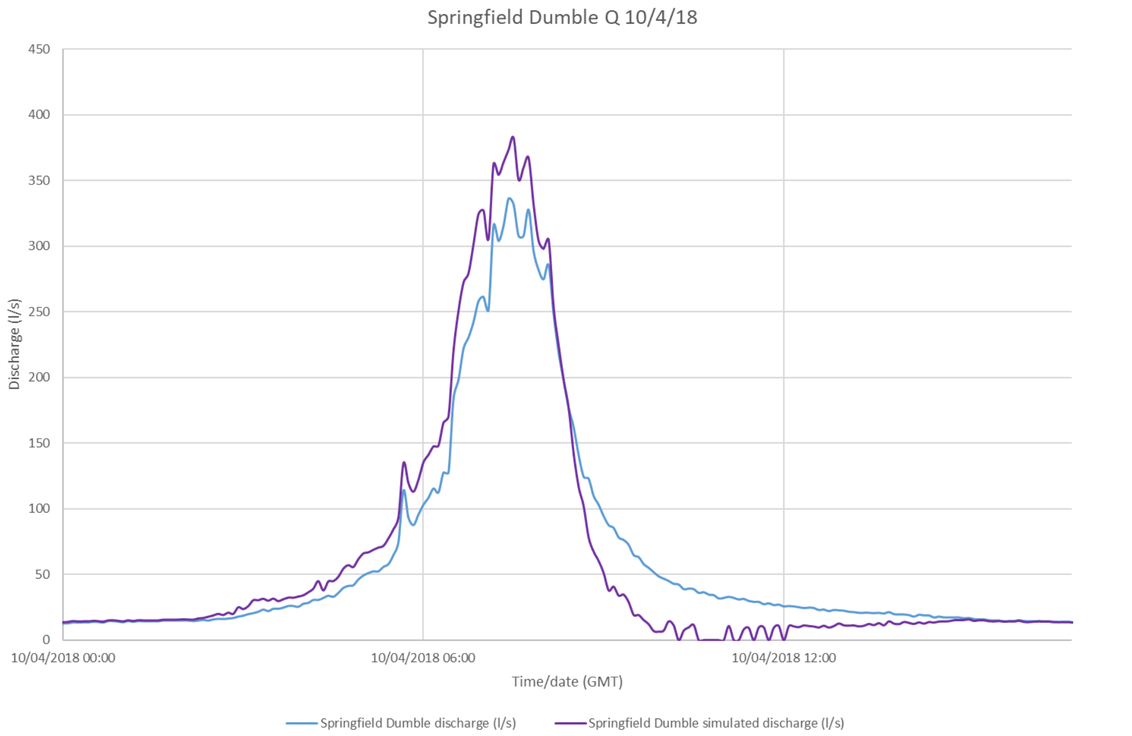

Figure C. 0.3 Observed and simulated Springfield Dumble discharge 10/4/18 using 2nd Sunnydale bund data

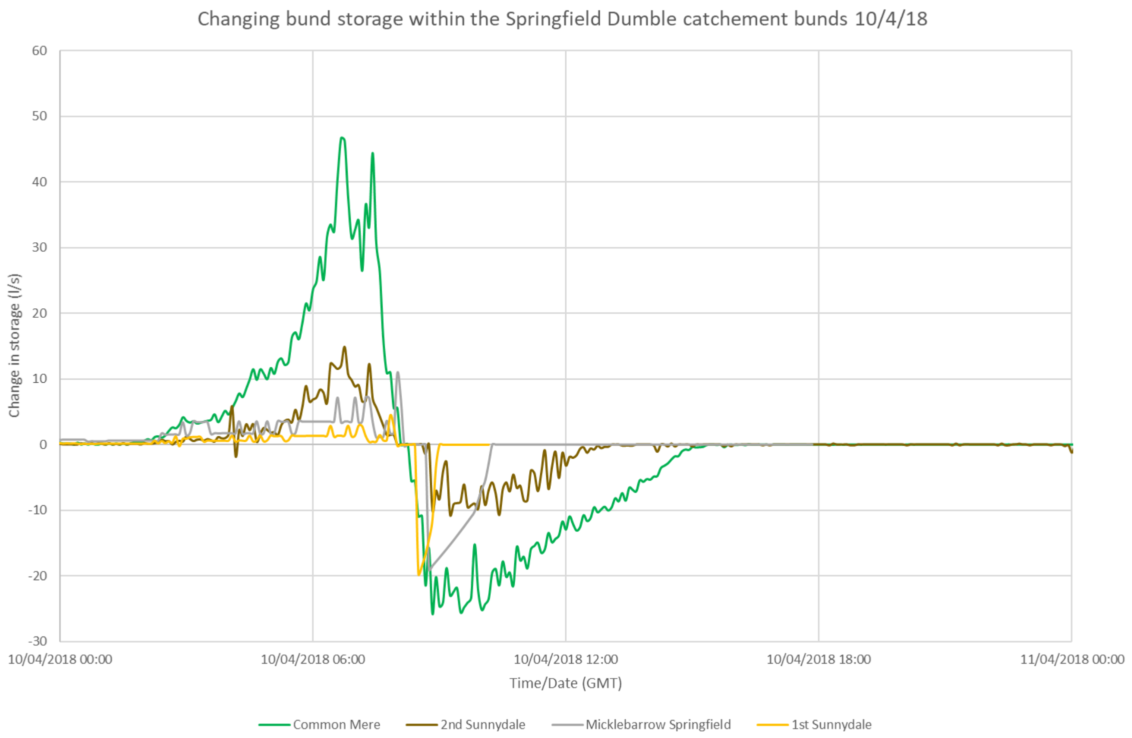

Figure C.0.4 Changing bund storage within the Springfield Dumble catchment bunds using 2nd Sunnydale bund data 10/4/18

Appendix D: Questionnaire sent to Southwell households

NOTTINGHAM
TRENT UNIVERSITY

This questionnaire has been created to gather data for a PhD project being conducted by Josh Wells and funded by Nottingham Trent University. It aims to gather data on attitudes to natural flood management in order to assess barriers to current use and will also give feedback on the Southwell Community Resilience Handbook which has been funded by the People's Postcode Lottery. The questionnaire should take no longer than 15 minutes to complete.

Please return your response in the freepost envelope provided.

All data will be anonymised and participants can withdraw their response within three weeks by emailing josh.wells@ntu.ac.uk and quoting their unique questionnaire number written at the top of the page. Participants have the right to withhold any answer.

I would like to thank you for your time in taking part in the survey.

If you have any queries, please contact my Director of Studies at jillian.labadz@ntu.ac.uk

Section 1: Experience and awareness of Flooding

1. **Have you ever experienced flooding in your house?**
   [ ] Yes [ ] No [ ] Prefer not to say
2. **Do you know the flood risk probability that applies to your house according to the Environment Agency?**
   [ ] Yes [ ] No **If yes, please state the probability** ____
3. **Do you know who to contact regarding flood risk management in your area?**
   [ ] Yes [ ] No **If yes, please state who** ____
4. **Please mark the box which you feel most applies to the following statement:**
   "I feel that I am an active stakeholder in flood risk management"

   [ ] Strongly Agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly Disagree
5. **Are you aware of any local flood action groups in Southwell?**
   [ ] No **Please go to Q7**

   [ ] Yes

   Please state the organisation name ____
6. **What experience of the flood action group in Southwell do you have? Please mark all that are applicable.**
   [ ] I have heard of it [ ] I am not a member but attend regular meetings [ ] I am an active member

   [ ] I am not a member but attend events organised by the flood action group
7. **Would you be willing to become more engaged with a flood action group in Southwell?**
   [ ] Yes [ ] No [ ] Undecided
8. **Please mark the box which you feel most applies to the following statement:**
   "I am protected from household flooding"

   [ ] Strongly Agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly Disagree [ ] Do not know
9. **Do you have any property level flood protection at your home?**
   [ ] Yes [ ] No

Section 2: Knowledge of Flooding and Natural Flood Management

10. Please mark the box which you feel most applies to the following statements:

Flooding is caused by:	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Do not Know**
Land use change	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of funding for flood risk management	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of structural flood risk management measures	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Climate change	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of urban drainage maintenance	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Natural events	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of dredging on main rivers	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of ditch maintenance in rural fields	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Channel modifications e.g. culverts and bridges	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of monitoring (river level/rainfall)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of public warning systems	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Development on the floodplain	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of personal level property level protection	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of catchment wide partnership approaches	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Paving over gardens	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of capacity of urban drainage systems	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Other (Please state)________________________________	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

11. Please explain what the term "Natural Flood Management" means to you.

____

____

____

If applicable, please state where you heard about natural flood management.

____

____

____

12. Would you like to learn more about natural flood management?

[ ] Yes [ ] No

13. Which sources do you feel would be the best to communicate this information to you?

[ ] Websites [ ] Newspaper/magazine articles [ ] Social media

[ ] Leaflets [ ] TV/radio programmes [ ] Academic journals [ ] Open days/site visit

[ ] Other (please state) ___________________________________

14. Is natural flood management included within any flood risk management plans for your local area?

[ ] Yes [ ] No [ ] Do not know

If so please state what the plans are

____

____

____

15. Please mark the box which you feel most applies to the following statements:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Do not know
Natural flood management is a viable option to reduce flood risk.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Natural flood management is expensive compared to other flood risk management strategies.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Current UK policy promotes the use of Natural flood management.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
I would prefer natural flood management in my area when compared to structural measures.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
More research needs to be done to prove that natural flood management can reduce flood risk.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Natural flood management can provide wider benefits beyond flood risk management e.g. wildlife benefits.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Natural flood management can increase flood risk.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
More funding should be allocated for natural flood management.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

16. Do you think there are barriers to the use of natural flood management?

[ ] No **Please go to Q18**

[ ] Do not know **Please go to Q18**

[ ] Yes

If yes please explain what you think they are.

____

____

____

17. How do you think the barriers you explained can be overcome?

____

____

____

18. Which stakeholders do you feel should be involved within natural flood management projects?

[ ] Environment Agency [ ] Lead local flood authority [ ] Land owners

[ ] Local residents [ ] Academic institutions [ ] Internal drainage board

[ ] Do not Know [ ] Other (please state)____________________________________

Section 3: The Southwell Community Resilience Handbook

19. **Please mark the box which you feel most applies to the following statements:**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The handbook has helped me understand the concept of community resilience.	[ ]	[ ]	[ ]	[ ]	[ ]
The handbook has increased my knowledge of the role of the agencies, authorities and services involved.	[ ]	[ ]	[ ]	[ ]	[ ]
The handbook has increased my understanding of my own role before, during and after an emergency/incident.	[ ]	[ ]	[ ]	[ ]	[ ]
The handbook has motivated me to be prepared for an emergency/incident.	[ ]	[ ]	[ ]	[ ]	[ ]
The handbook encouraged me to become more involved in community projects within Southwell.	[ ]	[ ]	[ ]	[ ]	[ ]
I will keep the handbook as a reference resource.	[ ]	[ ]	[ ]	[ ]	[ ]

Section 4: Background Information

20. **Age**
    [ ] 18-30 [ ] 31-50 [ ] 51- 70 [ ] 71+

21. **Gender**
    [ ] Male [ ] Female [ ] prefer not to say

22. **Income Range (£)**
    [ ] 0-10,999 [ ] 11,000 – 31, 999 [ ] 32, 000- 42, 999 [ ] 43,000+ [ ] Prefer not to say

23. **Postcode** ______________________________________

24. **Housing tenure:**

    [ ] Rented [ ] Owned occupied [ ] Other (please state) ______________________________

25. **Length of residency within Southwell**

    [ ] less than 1 year [ ] 1- 5 years [ ] 6-10 years [ ] more than 10 years

26. **Occupation**____

27. **Highest qualification held**____

Appendix E: Article written within the Southwell Flood Forum Community Resilience Handbook

What is Natural Flood Management and What Does it Achieve?

Natural flood management (NFM) aims to reduce flood risk by working with natural processes to slow and store water in the upper catchment. This in turn reduces the amount of water reaching downstream settlements at a given point in time. The result of such strategies can help to reduce flood peaks. However, benefits of NFM are not just limited to reducing flood risk. Wider benefits such as habitat creation, sediment capture, water quality improvements and combating climate change all can be achieved as a result of NFM implementation.

That sounds fantastic! So why is it not being used more?

Although there is some evidence of NFM being successful, such the Pontbren, Belford and Pickering projects, barriers still remain to its implementation. We need more evidence from successful projects which have been demonstrably proven to reduce flood risk. Due to the lack of evidence it is difficult to quantify how much capital can be protected by NFM methods. As current flood risk management policy requires a cost benefit ratio to be calculated, NFM is difficult to implement.

What are the methods of natural food management that exist?

NFM methods exist in many forms. Methods such as tree planting and riparian buffer strips aim to increase water infiltration into the soils, whilst methods such as bunding and wetland creation aim to retain water over short periods of time to be released slowly into the watercourses. Inserting large wooded debris into the upstream watercourses can hold back the flow forcing water onto the floodplain and increasing channel roughness, all of which slow the flow of water to downstream reaches.

Can you tell me about any examples of where natural flood management has been used?

"Trent Rivers Trust (TRT) has helped to deliver the 'Farming Floodplains for the Future' (FFF) project. This project delivered 9 schemes on farmland in the upstream catchment of the Sow and Penk, upstream of Stafford. All the schemes took place on working farms; the landowners were fully involved with the development of each scheme supported by the project staff. TRT also helped to set up and deliver the 'Farming and Water for the Future Project in the Upper Soar'. This scheme again worked with individual farmers to deliver 5 schemes on farms upstream of Leicester. Ruth Needham and Lesley Sharpe from TRT have agricultural and flood risk knowledge from a range of previous work to ensure farmers land and commercial interests were maintained throughout any proposed NFM project work."

Appendix F: Practitioner interview guide

<u>Introduction</u>

Could you please tell me a little about your role?

Where does NFM link in with this?

<u>Land owner barriers</u>

To what extent is land owner uptake a barrier? How do you think this can be overcome?

<u>Governance</u>

Can catchment partnerships help to overcome barriers to NFM implementation?

Can they cause conflict between organisations?

Can flood action groups help to overcome barriers to NFM?

Can the different responsibilities allocated to different bodies provide a barrier?

Can transboundary catchments provide barriers?

<u>Evidence</u>

Is there enough evidence to support the implementation of NFM?

Is there sufficient pre and post project monitoring?

Should there be more monitoring?

<u>Funding</u>

Do you think there is sufficient funding for NFM?

<u>Policy</u>

What aspects of current FRM policy support NFM?

Will this change when we leave the EU?

<u>Public attitudes</u>

What do you think public attitudes towards NFM are? Why?

<u>Final comments</u>

Do you have any more general comments that you wish to make?

Do you have any questions for me?

Appendix G: Land manager interview guide pre-NFM demonstration site visit

Question No	Section	Question	Rationale
1	Knowledge of Flooding	What do you feel are the main flooding issues in the local area?	Allows data to be gathered on the knowledge of flooding in the local area.
2		Is flooding as issue on your land?	If flooding is an issue then NFM could be beneficial as the waterlogged land could store water. Therefore this question is important.
3		What do you feel are the main processes that contribute towards flooding?	This question allows for a general overview to the perceptions of causes of flooding.
4		Do you think that land owners can manage their land to reduce flood risk?	This purposefully doesn't mention NFM but will gather data on land management issues.
5	Perception of NFM	What does the term "Natural Flood Management" mean to you?	Allows for data on the general knowledge of NFM by land owners to be gathered.
6		Do you currently have any NFM on you land?	Allows data on uptake rates to be gathered.
6a		What made you install the NFM?	Gives data to assess which factors positively influence uptake.
7		Do you think that upper catchment NFM is an option to reduce flood risk downstream?	Collects data on the perceptions of success for NFM.
8		What barriers do you feel exist to the uptake of NFM by land owners?	This question gives an insight into land owner perceptions of barriers to NFM.
9		Do you feel that you currently have enough support and knowledge to implement future NFM? Who would be best to supply this?	This question will allow a discussion on the support available to land owners and how it is best conveyed.
10	Willingness to Install NFM	Do you feel that some aspects of NFM could create wider benefits for the farm or wildlife?	This question will create a discussion on the wider benefits of NFM to both the farm and environment.
11		What kind of incentives do you feel would increase the uptake of NFM?	This will create discussion on how best to incentivise land owners to uptake NFM measures within their land.
12		Would seeing successful NFM on other sites increase the likelihood of uptake of NFM within your land?	This will allow for discussion around the idea of demonstration sites and if they will increase NFM uptake.
13	Other Feedback	Are there any other comments that you wish to make surrounding the topic?	This allows for the interviewee to make any other points which they fell they have not made during the interview.
14		Do you have any questions that you would like to ask me?	Question allows for any questions to be directed towards the researcher.
15	Monitoring	One part of my project is to collect data on stream response in Southwell. Would you be willing to allow the collection of baseline streamflow and water level data at a point on your land, to be used for gaining understanding of stream response to rainfall?	This will allow for further monitoring to take place and could build connections in the future.

Appendix H: Land manager interview guide post-NFM demonstration site visit

1. Natural flood management

Can you explain the term "natural flood management"?

Do you think that upper catchment NFM is an option to reduce flood risk downstream**? Why?**

Do you currently have any NFM on you land? What made you install the NFM?

2. Increasing uptake of NFM

Did the visit to Brackenhurst help you to understand more about NFM?

Do you feel that the site visit has changed your opinion of NFM?

What about behaviour towards NFM? Would you install NFM as a result of the site visit?

What kind of incentives do you feel would increase the uptake of NFM?

3. Barriers to NFM

Are there challenges that would prevent you from installing NFM on your land?

4. Wider benefits to land owners and ecology

Do you feel that some aspects of NFM could create wider benefits for the farm?

What about wildlife?

Would that incentivise you to use NFM on your land?

5. Are there any other comments that you wish to make surrounding the topic?

6. Do you have any questions that you would like to ask me?