# Examination of the impacts of a community Natural Flood Management (NFM) project within a catchment: An analysis of flood reduction capabilities and community reception.

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# Abstract

Flooding within the UK is set to increase in the future due to climate change, with significant rainfall events expected to affect local communities. Natural Flood Management (NFM) seeks to reduce flood risk by using and restoring natural processes as a sustainable solution. NFM has recently become popular with academics and government organisations, with many NFM projects ongoing within the UK, however, the effectiveness of NFM as a flood reduction tool is still debated. To increase the evidence base and to encourage its adoption, the UK government funded 34 community NFM projects in 2017. Research evaluating the impact these projects have on a local community is sparse.

A community based NFM project in Calderdale, West Yorkshire, which installed and has been monitoring NFM interventions since 2019 was studied. By evaluating the hydrological data collected by the project and the opinions of the local community a greater understanding of the effectiveness of community NFM projects on local flood risk and community reception was sought.

Analysis of the flood peaks and hydrographs indicated varied effectiveness of NFM interventions in reducing local flood risk. Of twenty potential flood events captured during an 18-month period, nine demonstrated a reduced flood peak timing, however the conditions, such as antecedent conditions or event rainfall, determining this effectiveness could not be established. In addition to hydrological analysis, a community questionnaire was produced and received 51 responses. Questionnaire results showed acceptance and knowledge of NFM was high within the community. Personal and community benefits were identified, including environmental gains and improved mental health, particularly amongst NFM volunteers. NFM community projects themselves and the secondary benefits they produced both increased community resilience to flood events.

This research is the first to establish that NFM community projects produce important secondary benefits to the local community and provides support for the continued use of such schemes even where flood risk benefits cannot be determined.

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# Abbreviations

**EA** Environment Agency

**GIS** Geographical information system

**NFM** Natural flood management

**SEPA** Scottish Environment Protection Agency

**STF** Slow The Flow (Calderdale)

**WHO** World Health Organisation

# 1 Introduction

Extreme weather events are predicted to increase worldwide at unprecedented rates because of global climate change (Iacob et al., 2014) resulting in rising sea levels, glacial retreat and a change in precipitation patterns leading to droughts and floods (Kiehl, 2011). Impacts from climate change are already being experienced and are increasing in many regions of the world (Aerts et al., 2014; Dankers et al., 2014, Di Baldassarre et al., 2010). Flooding is one of the greatest natural disasters experienced within the UK, with 21 major flood events occurring in the last 31 years (Met Office, 2021). Within the England, more than 5.2 million homes and businesses are at risk of flooding (Environment Agency, 2022). Climate change is likely to exacerbate and increase existing flooding putting many more people at risk (IPPC, 2022, Ashley et al., 2005, Hinkel et al., 2014, Jongman et al., 2014). For this reason, flood management strategies are regularly utilised to reduce flood risk. Wesselink et al., (2015) subdivided flood management strategies into five distinct categories: prevention, protection, mitigation, preparation, and recovery and are discussed in more detail in the following

Flood prevention requires changes in land use by relocating at-risk services whilst controlling new developments to reduce potential flooding (De Bruihn, 2004). Use of flood protection measures such as flood walls reduces flooding by protecting existing assets at risk from flooding (Nienhuis and Leuven, 2001). Flood mitigation strategies reduce the volume and adjust the timing of flood water by controlling rural land management to increase retention in upland areas whilst reducing urban drainage (Bechtol and Laurian, 2005). Early warning systems and disaster management plans are forms of flood preparation (Rubinato et al., 2019). If flooding is then unable to be prevented, flood recovery aims to help quickly rebuild areas that have been impacted (Wesselink et al., 2015). Within most management catchments, combinations of flood management strategies are employed to provide the greatest level of protection.

Flood protection strategies are most notably associated with flood management using hard engineering strategies such as dams, dykes, embankments and river diversions to prevent flooding. Whilst successful at reducing flood risk, the high initial upfront cost, maintenance cost, impact on surrounding environment and the increasing effect of climate change which is presently eroding current protections, many governments,

scientists and stakeholders have looked at other ways of reducing flood risk (Aerts et al., 2008). This has sparked interest in other flood management strategies such as flood mitigation. Flood preparation strategies rely on processes which provide increased protection from flooding. This interest has created new strategies for flood management, such as natural flood management (NFM) which looks to use 'natural' processes to manipulate hydrological and hydraulic processes at catchment and tributary scales to reduce the size of the peak flood at specific downstream locations (Lane, 2017). Flood preparation could include early warning systems and disaster planning to allow swift response when a flood event does occur (Wesselink et al., 2015). Flood preparation requires logistical management to prepare for the dispatch of commodities such as medical materials and rescue teams to allow for a quick response to a flood (Chang et al., 2007). Flood recovery specifically involves any process which helps rebuild and recover after a flood event occurs. This can include physical and monetary recovery through insurance and rebuilding (Wesselink et al., 2015) which can involve enormous expenditure (Lai et al., 2014). Flood recovery can also include mental and emotional recovery of the communities who experience flooding which can be a long process (Whittle et al., 2011, Sims et al., 2009)

Researchers have focused on reducing the physical risk of flooding through changes to the environment. Research is yet to commit the same resources to explore the interplay between physical and societal processes associated with flooding. Di Baldassarre's (2015) research suggested the importance of understanding this relationship to allow for greater accuracy when predicting future flood risk.

This chapter will explore the following: Impacts of flooding on communities, Flood resilience, community response to flooding, Natural flood management, Examples of NFM, NFM effectiveness and local communities and NFM.

## 1.1 Flood impacts on communities and community response

The initial impacts of flooding on local communities includes displacement of people as well as risk to life. Whilst danger to life is greater during the flood peak the after-effect of flooding can persevere long after the flood waters recede (Lowe et al., 2013).

Secondary stresses such as financial stress, loss and damage of property, disruption to business, health issues, relationship problems and emotional stresses are regularly reported after flood events occur (Tempest et al., 2017). Mental health issues within populations that have experienced flooding occur at a higher rate than in other populations (Ahern et al., 2005; Carroll et al., 2009; Stanke et al., 2012; Alderman et al., 2012; Fernandez et al., 2015). The effect of flooding and post flooding recovery on small businesses within rural contexts has been long overlooked in research and policy (Ingirige and Russell, 2015; Wedawatta et al., 2014) but local businesses can have huge impacts upon rural communities, economically and socially (Henderson et al., 2020).

Di Baldassarre et al., (2015) suggests that two types of physical and societal dynamics occur after a flood event. The first, the 'adaption effect' suggests that flooding impacts society's vulnerability to the effects of flooding. With recurrent flooding societal vulnerability decreases through increased coping and adaption capacities gained by the community. This is also supported by increased local and centralised government involvement to provide early warning systems, community engagement programmes and changes to land use planning after an initial flood event.

The second strategy is categorised as the 'command–and-control approach' (Sung et al., 2018). Historically, this approach has been prevalent I.e., the use of structural, hard engineered measures to try to prevent flooding whilst also enabling some predictability of the success of the interventions (Sung et al., 2018). This strategy prevents the regular flooding events occurring, however, when flooding does occur it is rare but catastrophic (Di Baldassarre et al., 2015). This is referred to as the 'levee effect' (Montz & Tobin, 2008). This effect suggests that an overreliance on hard engineered approaches can be disastrous (Di Baldassarre et al., 2015) as the coping skills and strategies needed for community resilience to be present are only developed through the regular experience of flooding.

Community spirit after a flood event is documented within research as a resilience measure (Boon, 2014). Boon (2014) noted that locals affected by flooding felt community spirit played a key role in helping a community 'band together' during and after a flood event. Boon (2014) also stated that community spirit played an important part in recovery from flooding. Research by Ntontis et al., (2018) suggested that

community spirit was mobilised after the 2015/16 flood events in York in those who had previously experienced flooding to help those who had not (whose perception was that they were ‘unprepared’ and needed support). This supports Di Baldassarre et al.’s (2015) adaption effect theory. Examination of a rural community’s wellbeing after a flood event found that community spirit was the single positive experience mentioned and that community spirit made it easier to cope with flooding (Walker-Springett et al., 2017). Walker-Springett et al. (2017), stated that rural communities provided support that was not available from authorities by creating networks and relationships between people in a community.

## 1.2 Flood resilience

Resilience is an increasingly important phrase used within many fields. The World Health Organisation (WHO) has highlighted the importance of resilience within health and within the sustainable development goals for adapting to the impacts of climate change (WHO, 2017). Within UK policy, national resilience is being seen as a key area for development (UK GOV, 2021). One of these areas includes community resilience to allow empowerment of society to adapt to the unexpected (UK GOV, 2021).

Within flood risk management, resilience is a relatively new concept which accepts the uncertainty created by natural disasters. Rather than preventing these uncertainties, resilience focuses on the ability to adapt and absorb these uncertainties (Disse et al., 2020). This approach is complimentary to flood risk management, which tries to reduce flood risk where possible using physical interventions (Disse et al., 2020). By integrating flood resilience, communities are protected from a broader range of hazards by creating flexibility of a community to cope (Disse et al., 2020).

Increasing resilience to flooding is rapidly becoming more important within research and government policy (Ntontis et al., 2018, Henderson et al., 2020). UK policy seeks to increase community resilience and capability to respond to local challenges by empowering communities (Henderson et al., 2020) through rolling back state led support, as seen in neoliberal politics, to create self-reliance in local communities to manage local services (Corry, 2014). Within the UK’s flood and coastal risk management policy there is emphasis on community level responsibility for planning

and resilience (Nye et al., 2011). This includes communities preparing for climate change effects, such as flooding, using collective local responses (Defra, 2012). Learning from previous flood events could allow communities to develop new solutions which would increase the community's security and resilience (Hegney et al., 2008). In practicality, national policies are not well suited to local level politics (Skerratt and Steiner, 2013) whilst promoting localism and community empowerment is complex (Henderson et al., 2020).

Liao (2014) suggests the notion in which communities cope with experiencing some form of flood exposure and its effects is an alternative suggestion for flood disaster mitigation. This relies upon the capacity of a community to cope with such a flood hazard. Sung et al., (2018) categorised this as a resilience-based approach which involves learning to live with flooding and the uncertainty which this entails. For this strategy to work effectively, building flood resilience is vital.

Sung et al. (2018) state that flood resilience can be seen as a scale of protections in which different strategies can exist: little or no control (allowing flooding to occur naturally), fixed control (through maintaining defences at a fixed rate regardless of changes occurring after implementation), rigid control (improving defences whenever flooding occurs to prevent future flooding) and adaptive control (the level of flood prevention fluctuates dependent on monitoring and learning by a society). Adaptive control can be deemed reactionary and most sensitive to recent flood events.

Within communities at risk of flooding, resilience is becoming increasingly important and with climate change it is likely that it will become more so in the future (Mehryar and Surminshi, 2021). Flood resilience is especially important with catchments where NFM is being implemented as the current knowledge of NFM suggests that it will not be effective during every flood event, which could mean some flooding is inevitable (Iacob et al., 2014). For this reason, personal and community resilience to flooding is highly important in NFM catchments

## 1.3 Communities' response to flooding

Most flooded communities contain a form of flood management or defence which the community relies upon to work successfully at reducing flood risk. Flood risk management projects can often involve a range of stakeholders, including a local community (Twigger-Ross et al., 2016) and, in some cases, flood management projects can be led by communities. Research is yet to establish the impact these roles can have on communities. Community flood groups can impact local flood knowledge by maintaining awareness of local flood issues (Forrest et al., 2017) and can provide emotional support to flood victims and support the vulnerable who cannot protect their homes (Forrest et al., 2017). Community level flood management can also provide a level of community empowerment which allows individual and communities to take responsibility for flooding (Nye et al., 2011).

Communities have long been actively involved in volunteering before and after disaster events (Rotolo and Berg, 2011). This has been through 'spontaneous' volunteering which involves people who are not affiliated with a non-profit organisation providing unpaid services to help during a sudden event, such as a flood (Harris et al., 2017). Within the past decade, communities have started to form flood action groups to become more actively involved with flood risk management in their catchment (Forrest et al., 2017). This has been encouraged through UK policy and has promoted greater localism and volunteerism within local flood risk management (Twigger-Ross et al., 2016). Volunteerism within flood management can include flood wardens, flood volunteers, flood alleviation volunteers and habitat volunteers (O'Brien et al., 2014). It is clear that in the UK, local communities and volunteers play a role within flood risk management (Twigger-Ross et al., 2016).

Whilst communities do play a key role in flood risk management, research into the effect of flooding on communities has primarily focused on the after-effects of flooding and the resilience of communities to rebuild after flooding (McEwan et al., 2017, Keating et al., 2020). This restricted approach to the study of flooded communities lacks greater insight by focusing on the primary problem and does not encompass the full experience in which flooded communities interact with their local environment (Haney and McDonald-Harker, 2017). Limited research has been conducted to

establish the opinions of local communities on the flood management of an area that was not directly linked with a flood event.

Traditional flood management strategies can have significant impacts on the environment and can threaten local ecosystems (Juárez et al., 2021). It is known that local environment and nature can have positive impacts on recuperation and mental health (Sonntag-Öström et al., 2015, Bratman et al., 2012). Greater connection to nature can improve memory, attention, concentration, impulse inhibition and mood (Bratman et al., 2012). Research is yet to explore the effect of changes to local environments due to flood management and how these could affect a local community.

## 1.4 Natural flood management

Increased population growth in urban areas is increasing the use of floodplains for development (Berndtsson et al., 2019) with over one-sixth of UK properties at risk of flooding (Environment Agency, 2022). Development on floodplains places many individuals at an increased risk of flooding by allowing populations to come in close contact with area more prone to flooding (Mori and Perrings, 2012). The use of traditional hard engineered structures built to reduce flood risk can be expensive to design, construct and maintain with two thirds of UK flood mitigation budget being currently spent on maintaining river and coastal defences (Ellis et al., 2021). Traditional flood management approaches can negatively impact ecology and water quality (Wingfield et al., 2019) and are therefore unlikely to pass as a catchment-based approach. Within small rural communities, the cost of traditional flood defences can outweigh the potential benefits (Wilkinson et al., 2014). For this reason, sustainable, cost-effective solutions to flood risk management are growing in popularity within UK policy (Wingfield et al., 2019). Recently there has been increasing interest in flood management techniques that modify land use and land management to reduce flooding through Catchment-Based Flood Management (CBFM) (Dadson et al., 2017). CBFM works at reducing flooding by changing the rate of discharge at strategic locations at specific time periods to manipulate how the high flows move through a catchment (Lane, 2017).

NFM, defined by Dadson et al., (2017) is a subsection of CBFM and works in several ways to reduce flood risk. By increasing attenuation of rainfall in areas which are less sensitive to the effects of flooding, such as woodlands, greenspaces and upland areas like moorlands and riparian areas (Dadson et al., 2017). NFM reduces rainfall runoff within areas of the catchment to reduce the rate of discharge into streams and rivers (Iacob et al., 2014). This slows the flow of water through a catchment reducing peak flooding to downstream locations (Bokhove et al., 2018) by allowing more time for rivers to diffuse the water (Lavers and Charlesworth, 2018). By changing the timing and volume of water which enters rivers, NFM can decouple river networks within the catchment (Lane, 2017). Through decoupling tributaries, maximum discharge into rivers is reduced by preventing the discharge from several tributaries entering the river system simultaneously (Pattison & Lane, 2012). This reduces the chance of rivers becoming overwhelmed.

The Scottish Environmental Protection Agency's (SEPA) definition of NFM is 'managing pathways and sources of floodwater through the use of natural hydrological and morphological processes' (SEPA, 2016). NFM SEPA (2016) states that techniques considered part of an NFM approach can include woodland planting, land management, creation and restoration of non-floodplain wetlands, upland drain blocking, gully woodland planting, afforestation on floodplains, creation of riparian woodlands and creation of wash lands (Lane, 2017). These measures encourage the restoration, enhancement and alteration of existing natural hydrological processes within rivers whilst also working alongside, reducing and excluding traditional flood defences which work to disrupt natural processes (SEPA, 2016).

The aim of these measures is to reduce flooding downstream by reducing and/or delaying flood peaks. Reducing and/or delaying flood peaks can reduce the peak discharge of a river downstream and therefore reduce flooding (Figure 1-1).

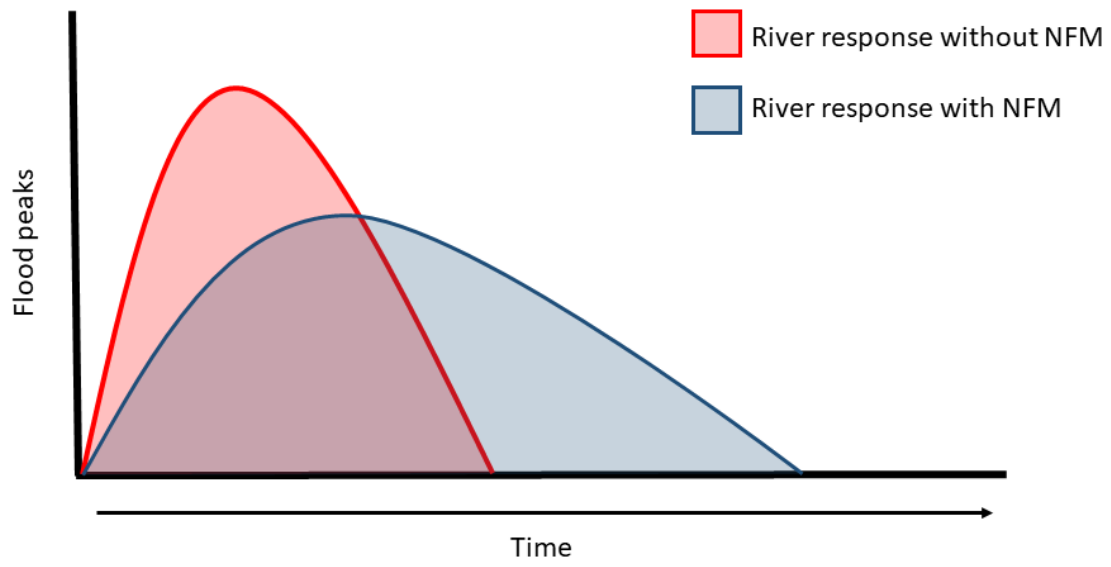


Figure 1-1 - A representation of the depth of flood peaks (mm) from rivers, during an event, with or without NFM.

When introducing NFM, several methods are typically used simultaneously throughout the catchment. NFM introduction requires a catchment wide approach to create a balance between attenuation and tributary inputs. Without a catchment wide approach, by decoupling several tributaries, it is possible to synchronise discharge from these downstream which would create further flooding (Bokhove et al., 2018). Dadson et al (2017) categorised NFM measures into three themes: 1. Retaining water through management of infiltration and overland flows e.g. changes in land-use practises such as forestry and woodland planting, creating permeable surfaces in urban areas and allowing field drainage thorough the culverts increasing soil aeration and vegetation management; 2. Managing connectivity and conveyance e.g. channel maintenance, river restoration and upland water retention ponds; 3. Making space for water through floodplain conveyance and storage e.g. NFM measure such as wetland creation, on/off-line storage areas and floodplain restoration.

SEPA (2016) separates NFM measures into 3 categories: Woodland creation, Land management and River and floodplain restoration. Woodland creation reduces runoff and increases flood plain storage through increasing infiltration of water. Afforestation of a site within a catchment increases the storage of water through evapotranspiration, improves soil structure and reduces overland flow through the creation of root networks within the soils. Although, during intense rainfall periods, evapotranspiration

is reduced (Dittrich et al., 2019) and correct placement of tree planting is vital (Marshall et al., 2014). Land management, including land and soil management practices and overland sediment traps, can reduce runoff and allow for greater sediment management (Dadson et al., 2017). River and floodplain restoration manages sediment and increases floodplain storage through the introduction of instream features, wash lands and offline storage ponds as well as river restoration.

Political and societal interests have grown in the use of NFM measures, and the UK government has formally integrated NFM into UK flood policy (Garvey and Paavola, 2021). Bottom-up approaches are regularly employed to facilitate the key activities required for NFM projects which has led to community NFM projects being implemented throughout the UK (Garvey and Paavola, 2021). The UK government has recognised the significant role community projects play in the introduction of NFM by supporting 34 ‘community’ and 24 ‘landscape’ level NFM projects (Defra et al., 2017). This funding was to enable community NFM implementation through a one-off payment with requirements for ongoing monitoring to add to the evidence base of NFM. To help with this ongoing monitoring guidance was produced for communities to establish the local impacts of NFM (Defra, 2019). Whilst NFM projects may be able to receive funding through other government organisations such as the flood and coast erosion risk management (FCERM) Grant in Aid (GiA) funding, this requires the production of a cost-benefit analysis. This can require a significant amount of data collection which can include flood modelling (Defra, 2019).

To prevent recurrent flooding events in the UK, NFM was introduced into catchments to protect housing, businesses and arable land (Merz et al., 2010) by local councils and government agencies in areas where large scale hard engineered structures were impractical. In rural environments, low populations sizes, lack of funding and restrictions on the location of structures (Short et al., 2018) can make hard engineered schemes impractical. This can make NFM an attractive option as, with strategic implementation, NFM is a lower cost strategy (Stroud District Council, 2017). NFM is often used alongside traditional engineering methods to try to increase the life span of structures (SEPA, 2016).

Whilst NFM has been implemented in catchments throughout the UK, producing quantifiable data of the effectiveness of NFM as a flood reduction strategy has proved

challenging, which has led to debate within scientific and government communities (Wingfield et al., 2019). Some government agencies and charities have deemed that radical change is needed to reduce flood risk and have therefore embraced NFM even without having an evidence basis for its effectiveness (Bokhove et al., 2019).

## 1.5 Examples of NFM

Successful NFM projects require the introduction of several NFM measures throughout the catchment, which reduce flooding through different methods (Dadson et al., 2017). These methods include leaky woody dams, gully stuffing, impounded storage and land management.

### 1.5.1 Leaky Wooden Dams

The introduction of wood as a river restoration tool has grown in popularity for both practitioners and academics. Currently, river restoration is a multimillion-pound industry within the UK with the greatest increase of interest in wood as a flood reduction tool (Grabowski et al., 2019). Historically, good river management methods advocated for the removal of obstructions from rivers to reduce channel resistance and improve river navigation, as it had been initially thought that the obstructions increased flood risk (Young, 1991). The river restoration movement has since evolved and now has many overlapping interests with NFM and both are using instream wood to reduce flooding downstream.

One of the most popular NFM methods is the use of leaky wooden dams. In-channel leaky “wooden” dam structures are instream structures which slow the flow during flood events by attenuating flood waters in-channel and diverting flood water to storage areas (Gregory and Davis, 1992). Leaky wooden dams can occur naturally when an accumulation of trees and branches are moved from riverbanks by strong river flows, partially or fully restricting flows (Muhawenimana et al., 2021).

In-stream features are employed within tributaries and streams to reduce flow velocities and increase the storage of water (Hankin et al., 2020). Leaky wood dams

are imbedded directly within stream flows. These dams commonly allow some water to pass through at low flows (Figure 1-2) and become active by damming water behind them at higher flows. This can create localised storage by creating a pool of water directly behind the leaky wood dam. This aims to slow the velocity and amount of water traveling through the stream at one time and thus reduces the amount of water entering larger river systems. Leaky wood dams allow for improved water quality by intercepting high sediment loads from the water and storing it behind the weirs (Barber & Quinn, 2012). Leaky wood dams are often built using locally sourced wood to reduce the risk of introducing diseases (Grabowski et al., 2019) This can make leaky wood dams an economical NFM measure. Secondary benefits are regularly seen when introducing leaky wood dams to rivers (Lo et al., 2021). Through this process, sediment loading is reduced within flood waters which can improve water quality (De Visscher et al., 2013) and increase in-channel roughness (Short et al., 2019). Leaky wood dams can increase biodiversity by providing habitats and food sources for biota (Braccia and Batzer, 2008) whilst also providing in river cover for fish and safe locations for reptiles and birds (Grabowski et al., 2019). The benefits instream wood can have for local ecosystems, often creating active habitats for many different types of organisms, are well established (Grabowski et al., 2019, Keeton et al., 2007).

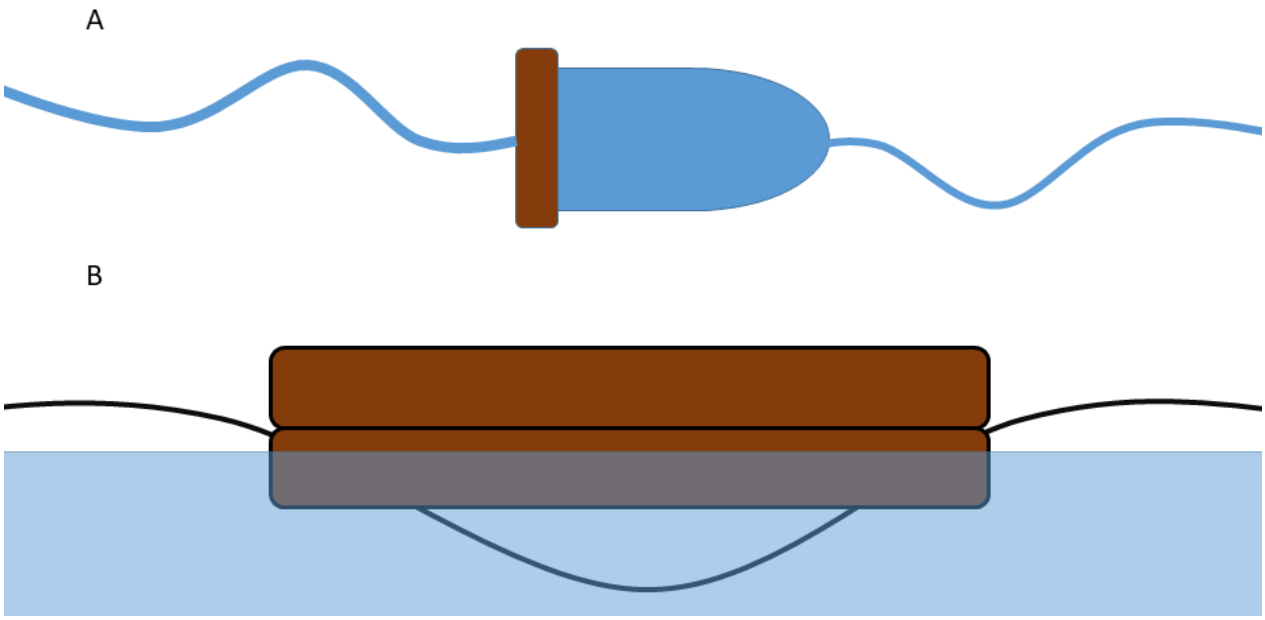

Figure 1-2- Representation of an active leaky wood dam during a high flow event with blue representing water. (A) Diagram of leaky wood dam from above pooling water (B) diagram showing instream NFM when active.

Man-made leaky wood dams often require ongoing maintenance, such as replacing wood and removing sedimentation (Barber & Quinn, 2012) from behind them. Without this ongoing maintenance (Grabowski et al., 2019), leaky wood dams become less effective, allowing greater amounts of water to discharge which reduces the depth at which the leaky wood dams become overtopped through sedimentation.

Modelling produced by Thomas and Nisbet (2012) within small Welsh tributaries located within a flood plain suggested that leaky wood dams could reduce flow velocities by up to 2.1 m/s behind dams which would slow flood peaks by up to 15 minutes over a 0.5 km reach. This indicates that the use of leaky wood dams could contribute to reducing flooding downstream, but little is yet know about the effect of leaky wood dams across upper and middle reaches within a catchment.

Research undertaken by Black et al. (2021) looked to establish the effect of lag times, catchment scales and different NFM measures across multiple sites. When analysing delays in lag times across different catchments, the most marked increase in lag times, up to 7.3 hrs, occurred in smaller catchments where the main NFM measure present was leaky wood dams. This suggests the importance of leaky wood dams as an NFM technique but cannot isolate the effectiveness of leaky wood dams, as other NFM measures were present within these catchments. Without understanding the effect individual measures have on events, a full understanding of the complexities of NFM as a flood reduction tool is not possible.

### 1.5.2 Gully Stuffing

Gully stuffing involves the infilling of erosion gullies which occur on land, in ravines and dry channels with natural debris, such as branches and logs, to impede water flow, reduce erosion and increase localised infiltration (Short et al., 2018). Channels most notably used for gully stuffing are usually seasonally activated during rain events.

Gully stuffing has been particularly successful within steep catchments where the geomorphology had previously prevented flood management (Short et al., 2018).

### 1.5.3 Impounded storage

Impounded storage areas can be offline or online and start storing water when a critical level is reached (Lane, 2017), diverting water into an area which will drain using evaporation and infiltration (Ouyang et al., 2015). Restoration of wetlands can increase storage of water during peak flow periods and reduce runoff entering river systems (Lane, 2017). Location of the wetlands can cause contention within a catchment as many historic wetlands are located on current agricultural land (Dadson et al., 2017).

### 1.5.4 Land Management

Many NFM methods require changes in land use practises. Specific changes can be made to agricultural practises such as reduction in livestock density or changes in tillage practices to reduce soil compaction or the use of buffer strips and buffering zones to reduce sediment runoff (Posthumus et al., 2008). Land management strategies, such as the restoration of peat and moorlands, can result in greater attenuation of water by reducing the depth of the water table and decreasing overland flow which is slowed by vegetation roughness and the soil types present in these habitats (Shuttleworth et al., 2019). Additionally, by reducing harmful practises, such as moorland burning, water storage can be increased (Shuttleworth et al., 2019).

## 1.6 NFM effectiveness

Within the UK, several well-known NFM projects have been implemented, including Belford, Pickering and Holnicote (Wingfield et al., 2019). Since then, other NFM projects have been established throughout the UK including areas such as Cumbria, Lancashire, Greater Manchester, Cheshire and Yorkshire (Flood Hub, 2021) and have typically been run by charitable organisations. In 2017, the Natural Environment

Research Council (NERC), allocated £4.4 million in funding for three research based NFM projects (NFM Research Program, 2021). This research is focusing on providing a greater evidence base for NFM's effectiveness (NFM Research Program, 2021). Additionally, NFM has been part of a 10-year policy documentation and interest in NFM has been widespread with NFM being adopted in small scale, unsystematic ways (Wingfield et al., 2019). Wingfield et al. (2019) argue that this is due to the focus on increasing the evidence basis of NFM which is complex if NFM is not applied at catchment scales.

At present, a lack of wider adoption of NFM measures has been linked with a lack of evidence of its effectiveness (Wingfield et al., 2019, Spray et al., 2009). Some individual methods, such as peatland restoration, have scientific backing (Wilson et al., 2011) but little research has established evidence of the contribution each method makes when a combination of methods at larger scales are used (Wingfield et al., 2019). Barlow et al., (2014) suggested that modelling indicates that NFM is suitable for small (>10 km) and medium catchments (>100 km) but verification of this is needed by further study. Low frequency high magnitude flood events are affected by several variables and catchments can respond differently, this can make collecting empirical evidence of the effectiveness of NFM complex and, therefore, reaching robust conclusions is difficult and may be unachievable for some catchments (Pattison & Lane, 2012).

To date, modelling has been widely used to assess the impact of NFM (Wingfield et al., 2019). However, collecting evidence which quantifies the effectiveness of NFM in reducing downstream flood risk through modelling is complex, with models rapidly escalating in complexity when assimilating catchment features which interact, combine and replicate (Metcalf et al., 2017). For this reason, computing models of NFM catchments struggle to process the complex interactions. Models can struggle to separate the effect of individual NFM measures due to hydrographic changes being hard to detect at short temporal or above local scales (Metcalf et al., 2017). Therefore, collection of field evidence from NFM projects is vital to increase the current knowledge base. However, research undertaken by van Leeuwen (Personal Communication, 2021) which looked to establish the effect of leaky dams on streams located in Coverdale, North Yorkshire using in-field data experienced data

inaccuracies which impacted data collected with data outliers present. This evidences the complexity of collecting field evidence of NFM's effectiveness.

Adoption of NFM has been relatively ad hoc in nature (Wingfield et al., 2019) with catchment wide adoption remaining limited until 'sufficient' empirical evidence exists. This limits the evidence basis for NFM which further reduces adoption of NFM. Whilst funding options are available for some NFM projects, such as the Defra funding, acquiring funding can be complex. Some funding bodies require complex cost –benefit analysis to be undertaken and the upfront cost of constructing NFM features can be particularly hard for those with limited funding (Defra et al., 2019). Waylen et al. (2018) found limited budgets for NFM and NFM projects being funding through a single one-off payment, which can mean ongoing costs such as monitoring and maintenance of NFM can be compromised. For this reason, communities are regularly volunteering to implement NFM to reduce costs (Garvey and Paavola, 2021). Catchment partnerships which introduce NFM are usually led by a host of charity organisations which have had little guidance from government (Wingfield et al., 2019).

As with other flood management measures, the scale of flood events will play a role in the effectiveness of NFM in reducing flood risk and once each individual measure reaches a critical limit NFM will become ineffective (Bokhove et al., 2017). Bokhove et al. (2017) state that for a 1 in 100-year event the current NFM measures proposed for the River Calder would only contribute 1% or less of the flood-excess volume required to mitigate against an extreme flood but that NFM measures can be upscaled to play a significant role in flood mitigation. Dependent upon the different variables inputted when calculating the combined effect existing reservoirs and NFM have on flood reduction, effectiveness can vary by as much as 0% to 93%. When considering NFM's ability to respond to large flood events variables such as levels of infiltration, amount of water stored and overall saturation of the ground during extensive rainfall can all have an effect (Iacob et al., 2017). They can all significantly affect NFM's ability to work effectively but this is not exclusive to NFM and would affect other hard engineered strategies also. Research has suggested that the scale of implementation has not yet reached the extensive levels required to function in such low frequency events and further scaling up of existing NFM projects would be required to conclusively determine NFM's effectiveness on these events (Iacob et al., 2017).

Antecedent conditions can play a significant role in determining the effectiveness of NFM measures. The aim of NFM is to slow water through the catchment at certain timescales (Bokhove et al., 2018). If, due to preceding weather conditions, the catchment is already saturated the ability for infiltration will be compromised, increasing runoff and decreasing NFM's effectiveness (Bokhove et al., 2018). Leaky dam effectiveness can be influenced by antecedent conditions, event rainfall, catchment characteristics and channel geomorphology (McCuen, 2005, Black et al., 2020). The effect of antecedent conditions on the effectiveness has been stated (Black et al., 2020) but no research has yet quantified this effect. This suggests that NFM should not be seen as a 'no regret' measure (Iacob et al., 2014) and NFM implementation should be carefully considered, further highlighting the complex nature and diverse scenarios in which NFM's effectiveness can be altered.

Gathering evidence about the effect of NFM requires significant time as many NFM measures, such as tree planting, can take years to fully establish, with many benefits not being fully realised for many years (Black et al., 2021). NFM is not generally known as a 'one-size' fits all approach and requires tailored and local adaptions dependent upon several factors such as, underlying geology, catchment size and current land use. This can further reduce the evidence base for NFM as many studies already conducted are only applicable to catchments which have similar features to those previously studied, which is likely to be rare. Therefore, in order to increase the evidence base, data from many NFM sites must be collected.

## 1.7 Local communities and NFM

Involvement of communities within flood risk management is increasingly being encouraged by governments to facilitate 'co-produced' flood risk governance between authorities and local communities (Mees et al., 2018). This is especially prevalent in NFM projects which can require a significant number of stakeholders which are specific to catchments (Garvey and Paavola, 2021). Funding organisations have recognised this shift and the 'Partnership Funding' model has been increasingly used within NFM projects to provide community co-funding of flood measures (Defra, 2011). The European Union have also highlighted the need for public participation in flood

management (Penning-Rowsell & Johnson, 2015). For this reason, community cooperation in NFM projects is increasing.

Community NFM projects can be created with external facilitation by local and national governance or through independent community initiatives by community flood groups in response to flood events (Garvey and Paavola, 2021). Most NFM projects are operated as partnerships involving several stakeholders, including, but not limited to, local community groups, charities, and institutional actors (Garvey and Paavola, 2021). This ensures that community groups and other stakeholders can provide NFM measures that are delivered within the context of broader governance strategies (Paavola, 2009). Whilst the main aim of community NFM projects is typically the reduction of flood risk locally, the partnership approach allows for greater representation of local views within NFM and multiple benefits. Garvey and Paavola (2021) reported that community NFM groups, such as those in Pickering and Calderdale, were involved with the physical implementation, informational, advocating and strategy of NFM.

Research has attempted to evaluate the impact that NFM flood management may have on communities. Pioneering research by Howgate & Kenyon (2009) first assessed community and landowner cooperation when delivering NFM within the Scottish borders. Findings indicated a willingness to cooperate with NFM, the belief that NFM would provide beneficial impacts and the communities upstream were willing to adopt measures to help the communities further downstream and support them in dealing with flood risk. The researchers noted that poor communication of the project to the local community did create hostilities, but the benefits outweighed the negatives.

Garvey and Paavola (2021) have more recently explored the impact of community flood groups in NFM projects within Pickering and Calderdale. The increased participation of community groups improved the community's access to conversations involving flood management and raised the local profile of NFM projects. The community were able to become involved with the delivery and implementation of NFM measures as well as help increase the evidence base of NFM. This research concluded that a community-centric, catchment-based approach was needed to create successful NFM projects.

Within the context of broader flood policy, increasing community resilience to flooding is a priority established by the UK government (Ntontis et al., 2018, Henderson et al., 2020). As part of this, the UK government found that local community flood action through empowerment and self-reliance has been increasingly important (Henderson et al., 2020). Community resilience is particularly important for catchments with NFM projects as, during some flood events, NFM may not be able to provide the necessary levels of protection to prevent flooding (Iacob et al., 2014). However, community NFM projects could still build community resilience to flooding through community-based flood action (Garvey and Paavola, 2021).

Research has been conducted to establish the role and effect stakeholders can have on NFM projects. Bark et al., (2021) conducted a UK wide study of the views of stakeholders on NFM. Results showed a vast variation in stakeholders' opinions of NFM with some viewing NFM as a "no-brainer" whilst others, mostly farmers and landowners, having a more cautious view.

Multiple organisations and stakeholders are currently actively involved in all aspects of NFM projects (Garvey and Paavola, 2021). Currently there are no official guidelines on the role or roles that different stakeholders i.e. government bodies, local councils, private companies, charities, or volunteers should play in the various aspects of NFM to optimise NFM's impacts. Bark et al., (2021) reported that stakeholders agreed that NFM funding should be shared across society, but disagreements around the details of payments were present. This lack of clarity exemplifies the need for research into the views of the community about the roles of each organisation involved within each stage of NFM.

Flood management methods are regularly employed using top-down approaches involving government agencies and councils (Garvey and Paavola, 2021). NFM projects using top-down approaches require an external level of management from institutions, but some communities have undertaken a bottom-up approach to introducing NFM and are independently initiating NFM projects (Garvey and Paavola, 2021). Unlike some traditional methods, NFM regularly requires cooperation from stakeholders such as landowners and local communities (Howgate & Kenyon, 2009) but guidance on how to actively integrate communities into NFM projects is sparse (Garvey and Paavola, 2021). The willingness of communities and other stakeholders

to cooperate with NFM strategies is vital for the introduction of NFM. The community's expectations of the beneficial impacts that NFM could provide a sense of responsibility to reduce flood risk (Howgate & Kenyon, 2009). Many NFM projects require community participation in the form of volunteering (Garvey and Paavola, 2021). Therefore, a failure in these expectations being fulfilled could impact future willingness to volunteer. Previous studies have highlighted the benefits experienced by volunteering in ecological restoration (Miles et al. 1998) but research has not established this for NFM volunteers.

Community NFM research is still in its infancy, and currently focuses on the benefits the community can provide for NFM rather than the benefits that NFM could bring to local communities. Research has suggested that NFM could provide multiple benefits (Iacob et al., 2014) and the evidence basis has been strengthened by the Environment Agencies' 'Working with Natural Processes - Evidence Directory (Environment Agency, 2021). Whilst this evidence basis is growing this area of scientific research is still in its infancy. Additionally, to date, no research has investigated the potential link between community led NFM schemes on the individuals living within a community, especially those who actively volunteer to deliver NFM. This research fills this research gap by establishing the impact NFM projects may have on and for a local community.

## 1.8 Aims and objectives

The overall aim of this research is to assess the effectiveness of community led NFM projects in delivering flood risk and community benefits.

In order to address this aim, the following objectives are identified:

- Use community collected hydrological data to establish the impact of NFM measures on reducing flood peak timings.
- Use a questionnaire to identify community opinions on NFM, its benefits and community led NFM projects.

# 2 Methods

## 2.1 Study site

Calderdale was chosen as the area for this research due to it having a well-established NFM programme with a significant amount of community engagement by several grassroots organisations which had been supported by several institutions. Slow The Flow's NFM projects within Calderdale had been ongoing since 2015. Collected but unanalysed data was available and NFM had matured, meaning the opinions collected should reflect this and should provide an understanding of what impacts NFM projects are having on a local community.

Calderdale is located within the county of West Yorkshire and makes up one of the five districts along with Bradford, Leeds, Kirklees and Wakefield. Calderdale includes several towns such as Halifax, Hebden Bridge, Todmordon, Ripponden, Sowerby Bridge, Elland and Brighouse. The population of Calderdale, as of mid-2020, was 211,400 people (Calderdale Council, 2021).

Calderdale has experienced frequent and disastrous flooding which has had significant impacts on the area. The Calder River is the main river in Calderdale with several towns located in close proximity to it (Forrest et al., 2019). Towns that are most regularly flooded include Hebden Bridge, Todmorden, Sowerby Bridge, Mytholmroyd, Elland and Brighouse. The earliest flood recorded in Calderdale occurred in 1615 and destroyed Elland Bridge (Eyeoncalderdale, 2021). Within the last 20 years, flooding has occurred 20 times in Calderdale, with several flooding events being experienced within the same year (Eyeoncalderdale, 2021).

The site selected for hydrological analysis is located north of the Hebden Bridge town within the Hardcastle Crags Estate. Two tributaries were selected for study, one being a control with no NFM interventions and the other being a stream with leaky wood dams installed. These streams, whilst being located within the National Trust's estate, have been managed by the local charity STF Calderdale. Both tributaries connect to the larger Crimsworth Dean Beck, which in turn, feeds into Hebden Beck.


Figure 2-1 - A locational map of the loggers placement within the two tributaries

Flooding is prevalent within Calderdale due to several factors. Towns located on the River Calder experience significant river and hillside surface run-off which is exacerbated by heavy rainfall (Forrest et al., 2019). Once the river reaches capacity, it overspills into the nearby canals which leads to the area becoming quickly overwhelmed by the increased flows (Forrest et al., 2019). This leads to both fluvial and pluvial flooding.

Flooding in winter 2015 devastated several areas across the UK with Calderdale experiencing a series of three flooding events of the town between 14/10/2015 to 26/12/2015. Many of the river monitoring stations within Calderdale received their highest readings on record during the 26/12/2015, an event referred to as the Boxing Day Floods. This flooding event followed 60 mm of rainfall occurring in Pennine areas within a 24-hour period with some locations receiving over 100 mm (Calderdale Council, 2017), with the ground already being saturated from high rainfall throughout December. Hebden Bridge, Sowerby Bridge, Elland and Brighouse all flooded during this event. The aftermath of the flood was devastating with 3,500 homes and businesses affected (Environment Agency, 2016).

Hebden Bridge was largely undefended due to the topographical constraints of the catchment (Maskery et al., 2016). After recovering from the devastation of the 2015 floods, improvements to increase flood resilience were deemed most suitable for the area (Maskery et al.,2016). Although hard engineering was and is currently being considered, research undertaken by Maskery et al. (2016) stated that such measures would be unpopular due to concerns that they would significantly affect the town's aesthetics, specifically the town's attractive and historic setting, upon which the local economy relies. For these reasons, a variety of NFM measures were deemed the most suitable approaches for the area. The introduction of NFM into Hebden Bridge and the surrounding towns was established through partnerships within Calderdale involving several stakeholders, including the Environment Agency, Calderdale Council, the National Trust and Yorkshire Water as well as several local community groups (Slow The Flow, 2021).

After the 2015 Boxing Day floods, the local community group STF was formed as a grassroots organisation with the aim of reducing flood risk by using natural processes (Slow The Flow, 2021). STF is part of the SOURCE partnership, which contains grassroots, public and third sector organisations who are actively involved with NFM within the catchment (Maskery et al., 2016). The SOURCE partnership was formed to allow greater partnership between these stakeholders who share the collective aim of providing ecological restoration to the River Calder. Community groups provide a 'community led' approach for NFM within Calderdale and NFM became one of the four main pillars of the Calderdale Flood Action Plan (Environment Agency, 2016). Since its formation, STF has looked to build NFM measures within Hebden Bridge on property owned by the National Trust through volunteering (Slow The Flow, 2021). Other local community groups who have overlapping interests, such as Treesponsibility, Todmorden Moor Restoration Trust and Calder Futures also participate in NFM measures, as well other environmental projects within Calderdale

The Calderdale catchment is shown within Figure 2-2 Calderdale has elevation ranging between 45 AOD and 508 AOD. The minimum elevations within Calderdale are located mostly to the east and the maximum elevations to the north, west and south. Rivers located within Calderdale, shown in Figure 2-2, are located throughout

the catchment. The catchment is characterised by relatively flat uplands and steep sided cloughs.

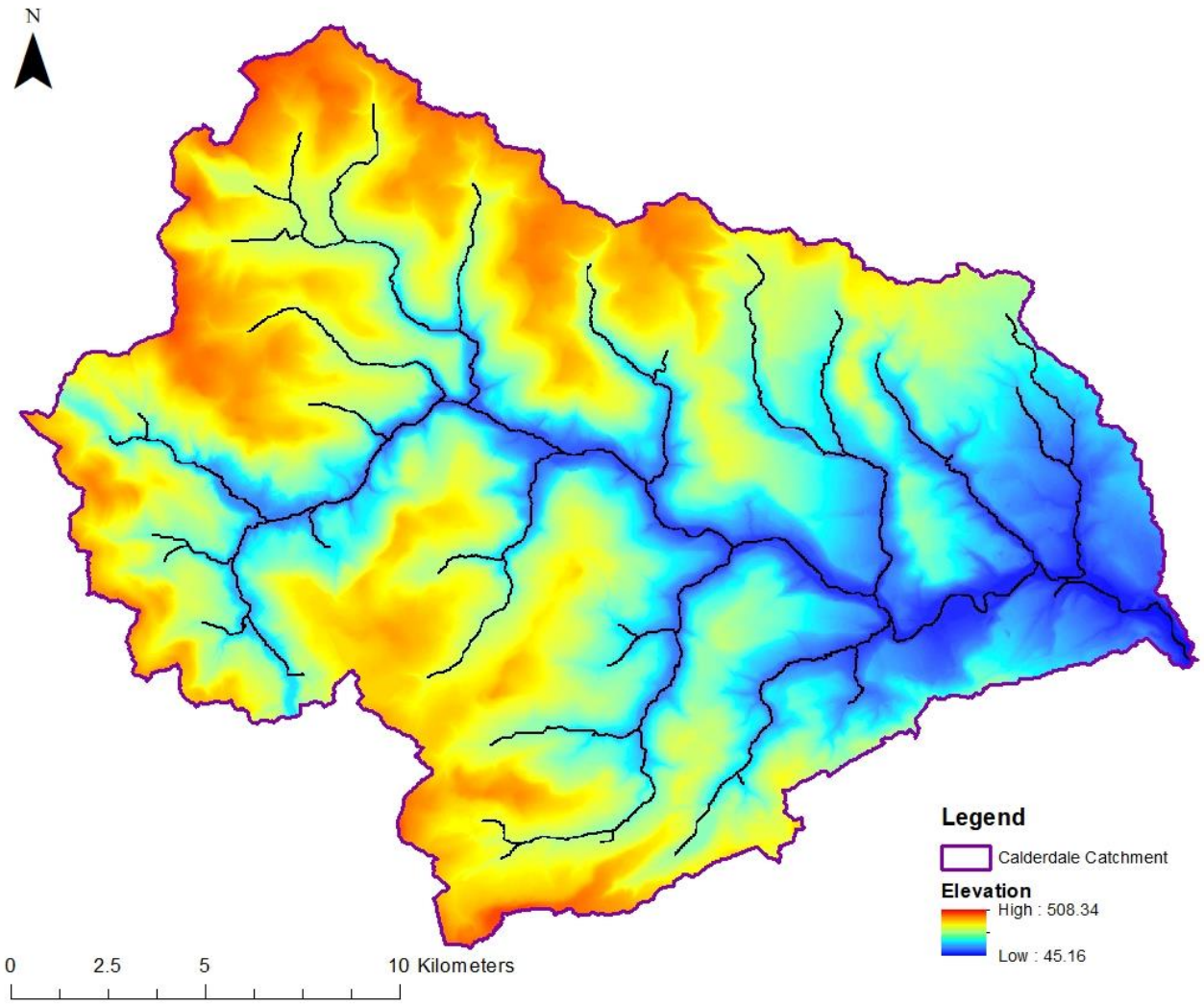


Figure 2-2– DTM of the Calderdale catchment produced from 5 metre data obtained using EDINA Digimap service (Ordnance Survey, 2018).

## 2.2 Calderdale

The underlying geology of the catchment is sedimentary rock. Millstone Grit is located to the north, west and south of the catchment, specifically under the study site of Hebden Bridge (BGS, 2021). The Millstone Grit, which includes mudstone siltstone and sandstone, was formed between 313 to 326 million years ago during the Carboniferous period. These types of rocks are usually formed in river settings from sand and gravel deposits (BGS, 2021). Bedrock located to the east of the catchment includes areas of Pennine Lower Coal Measures Formation which include mudstone, siltstone, sandstone, coal, ironstone and ferricrete (BGS, 2021). This was formed approximately 313 million years ago during the carboniferous period in swamp, estuary and delta settings which were regularly inundated by seas, estuaries and/or deltas.

Superficial deposits within the Calderdale catchment are presented in Figure 2-3A. Most notably, peat superficial deposits are located at the north and south of the catchment at the highest elevations. These deposits were formed after the last Ice age within environments of significant organic accumulations (BGS, 2021). Superficial deposits of Alluvium formed from clay, silt and sand around 2 million years ago within river environments. These deposits are located near the Calder river's current location at the lowest elevations of the catchment. No other superficial deposits were present in Calderdale.

The Calderdale catchment has diverse land uses ranging from large areas of upland bog to urban areas (Figure 2-3B). The upland blanket bogs present at higher elevations are areas of peat which are significant for the hydrology of the catchment as they can reduce runoff generation, prevent soil erosion and improve nutrient retention (Bragg, 2002) however, they can also increase runoff due to raising the water table (Haapalehto et al., 2011). Degradation of moorland areas through human activities including grazing, drainage and burning, compounded by climate change, can significantly reduce the capability of the moorlands to reduce flooding downstream (Pilkington et al., 2015).

Grassland is present within Calderdale at mid to low elevation levels close to the rivers of the catchment and urban areas. Grassland is often susceptible to increased runoff (Archer et al., 2012). Woodland is predominantly broadleaf clough woodland, located on relatively steep slopes throughout the catchment. Coniferous woodland is sporadically located within the catchment. Woodlands are important hydrologically to a catchment as they can increase infiltration, increase storage and reduce flood peaks (Thomas and Nisbet, 2012).

Urban settlements are located within the river basins and to the east of the catchment with the largest urban area located in Halifax. Suburban areas are dispersed around urban areas and river basins. It is also noted that urban and suburban areas are located close to the river basins and at lower elevations which makes them susceptible to flooding.

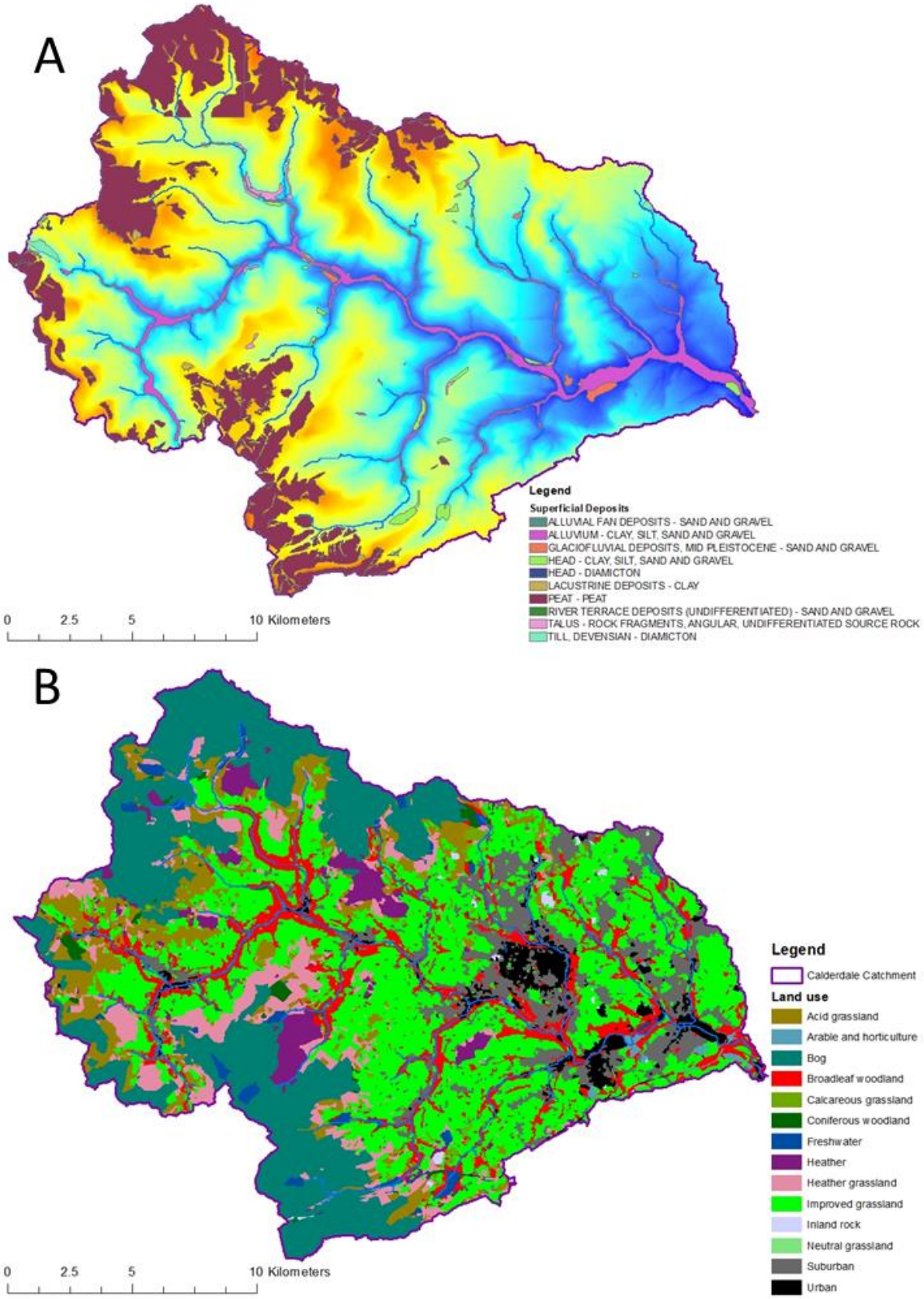


Figure 2-3 - Calderdale's geology and land use. (A) superficial geology (B) land use within Calderdale using EDINA Digimap service (Ordnance Survey, 2018)

## 2.3 Hydrology methods

### 2.3.1 Monitoring setup

In 2019, STF Calderdale began monitoring two tributaries at Hardcastle Crags Estate, Hebden Bridge. These two tributaries are known as Tributaries 2 and 3. Within each tributary v-notch weirs were installed at the top and bottom of the reach (Appendix B). Pressure transducers were installed in both streams in March 2019 to record river depth and temperature. Pressure transducers (InSitu Inc. Rugged TROLL® 100) were installed in the pool behind each v-notch weir to record depth via pressure. The V-notch weirs were installed to help improve accuracy at low flows. Within Tributary 2 (T2) 10 in-stream 'woody dams' were installed between the upper and lower V-notch weirs, whereas Tributary 3 (T3) acted as a control with no interventions installed. A paid contractor was responsible for the installation and management of the instrumentation and the data collection from 2019. Data collection is ongoing until March 2022. The data from both tributaries collected between 2/3/2019 and 29/9/2020, a period of approximately 18 months, was analysed for this study. In addition to the pressure transducers time lapse cameras (Brinno TLC200) were also installed behind all four of the v-notch weirs. Individual images were captured at 10 min intervals and automatically converted to video.

On 17/5/2021, a site visit was undertaken that identified several issues with the site set up that impacted on data quality. All four v-notches were found to have been compromised to some extent. The v-notch weir at the top of T3 had completely failed with scour evident on both sides, allowing water to flow around the edges of the weir rather than through it. The other v-notch weirs also exhibited some scour, meaning not all flow passed through the v-notch, however it was unclear when this scour occurred. Significant sedimentation was also observed behind all the v-notch weirs. The most severe sedimentation was observed at the top of T2 and the bottom of T3 (Appendix B). As the period of sedimentation build-up was unknown it was not possible to calculate sedimentation rates. Where the level of water below and above the base of the v-notch and the angle of the v-notch is known it is possible to calculate discharge using an empirical equation. However, because the sedimentation occurred at an

unknown rate it was not possible to calculate discharge from the recorded water levels. Therefore, the following methodologies were selected to best utilise the available data.

## 2.3.2 Hydrological analysis

Prior to analysis several methods were employed to standardise the data. First the logger data for each v-notch weir was consolidated into a single record using R-Studio and plotted to allow a visual assessment of the entire record. This visual assessment identified areas of anomalous data. These included periods of extreme responses, both negative and positive and step changes in levels that were unlikely to have been natural. Periods of significant errors were noted (Appendix B) and, where possible, periods of significant disruption were manually corrected. These typically occurred after downloading when the sensor was not installed at the same level as prior to downloading.

Due to logger memory capacity and volunteer availability the interval at which data were logged changed part way through the record. Between 02/03/2019 and 24/06/2019, data was collected at 2-minute intervals, however between 27/06/2019 and 29/09/2020 data was collected at 15-minutes intervals. To standardise the data and allow comparisons between the two-time intervals used, the 2-minute data was converted to 15-minute data by averaging the 14- and 16-minute readings.

Events selected were initially chosen through visual analysis of the hydrographs. Every single peaked event recorded on the hydrographs during the 2-year period was chosen. This was to allow the greatest number of events as possible to be analysed, however, it should be noted that these events were not checked for compromises to the weirs. Once these events were selected, their rainfall return periods were calculated using daily rainfall data collected by the Environment Agency from Gorpley Reservoir, located (Kumar and Bhardwaj, 2015; Equation 1):

$$Recurrence\ interval = \frac{n+1}{m} \qquad \text{Equation 1}$$

where $n$ is the number of years on record and $m$ is the rank of observed occurrences when arranged in descending order.

From the events chosen for further analysis, three events with a return period longer than one year were identified (see Appendix B), with a calculated return period of 3.4, 3.7 and 17 years respectively, whilst the other events selected from visual analysis had return periods of less than 18 months. In total 19 events were selected for further analysis. To compare the effect of leaky wood dams against the control tributary, hydrographs for T2 and T3 were produced for all 19 events using the rainfall and level data.

In order to assess the control catchment, the catchment area for both river reaches were calculated using ArcGIS. A Digital Terrain Model (DTM) of the site was downloaded from Digimap (2021) in order to calculate the catchment for the tributaries. At the time of analysis only a 5-metre DTM was available for download. Visual inspection of the watershed of the tributaries using ArcMap showed inaccuracies. This was likely to be due to the low resolution DTM used. To try and address this, a method to 'burn' the channels in to the DTM was used (Lindsay, 2016). This involved subtracting 100m from the DTM along the length of the tributary. After using the 'burn' method, Strahler order (Hughes et al., 2011) was used to determine the watershed of each of the tributaries (Figure 2-4). Upon reviewing the outputs, the catchment area of the two tributaries were found to be significantly different in size making them unsuitable for comparison. Therefore, based upon the significant differences in catchment size and visual analysis of the record hydrographic peaks, the data for the control tributary was discarded from further analysis.

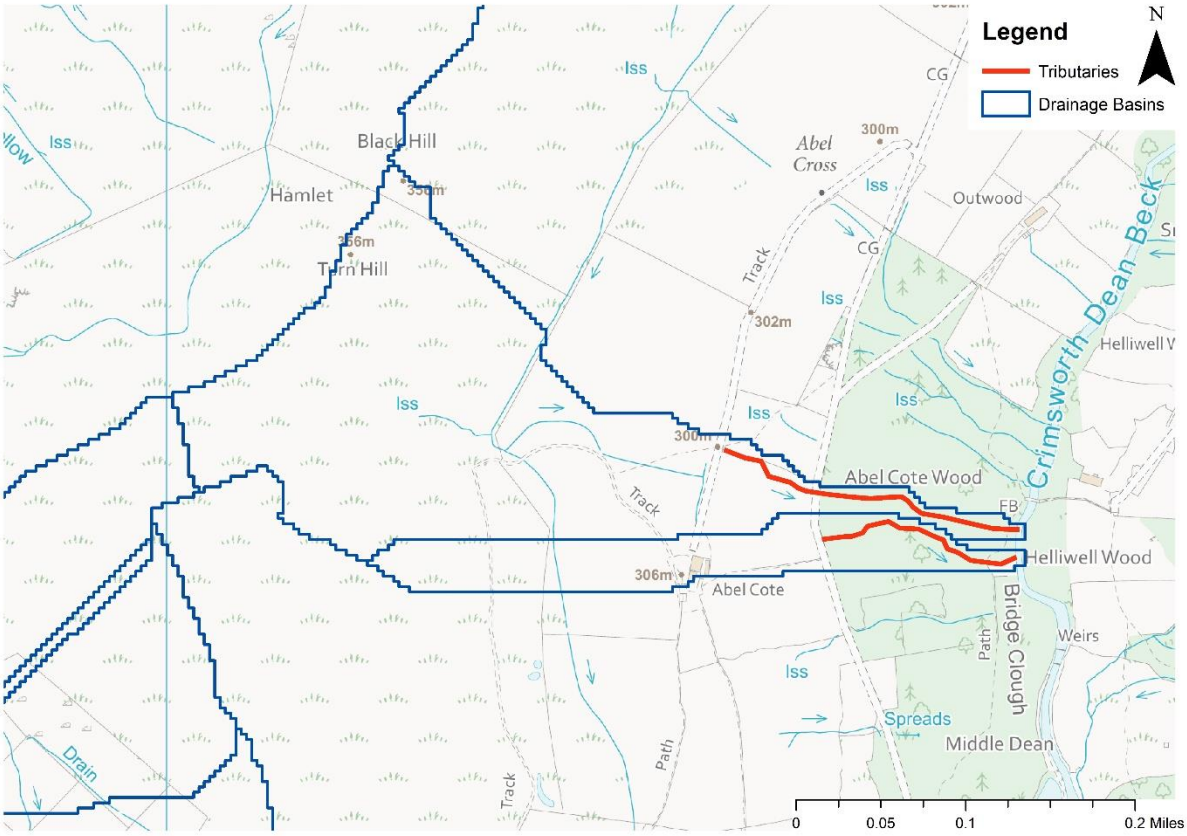


Figure 2-4 - Tributaries selected for study and their individual drainage basins

Due to the sensitivity of the pressure transducers, smoothing was undertaken to reduce data noise within the hydrographs using simple symmetric rolling averages for each event. These were calculated for all events using a moving window of 3 and 5, with the average determined by both the previous and subsequent values. This was used to aid the observation of the general data trends and to reduce outliers within the data set. The rolling average of 3 was used within event coding for maximum accuracy of data and the rolling average of 5 was used for hydrograph outputs as this outlines general trends due to smoothing of the data for visual analysis. The original data set was used for subsequent statistical analysis (section 3.1.1) with the significant outliers removed.

To understand the effect of antecedent conditions on NFM, the rainfall data was analysed for the selected events. This process allowed the isolation of different variables affecting each event and also the identification of events where NFM was successful or unsuccessful in terms of slowing the flow of water between the top and bottom logger. The antecedent, rainfall and level variables used for the subsequent analysis are shown in

Table 2-1. Output tables for each variable can be found in Appendix B.

Table 2-1 - A list of all variables studied

| **Antecedent conditions and event rainfall collected** | **Flow variables collected** |
|---|---|
| Start of rainfall (h:m) | Date and time of start of event (Day, h:m) |
| End of rainfall (h:m) | Initial depth (mm) |
| Rainfall duration (min) | Time between initial depth and peak depth (h) |
| Total rainfall in event (mm) | Peak depth (mm) |
| Mean rainfall per hour (mm/h) | Date and time of peak depth (day, h;m) |
| Peak rainfall amount (mm) | Depth 12 hours after peak (mm) |
| Peak rainfall time (h:m) | Depth 24 hours after peak (mm) |
| Total rainfall 3 days antecedent (mm) | Time between peak rainfall and peak depth (h) |
| Total rainfall 24 hours antecedent (mm) | Difference in peak depth and initial depth (mm) |
| | Difference in initial depth and depth 24 hours after peak (mm) |
| | Time between start of rainfall and start of event (h) |

Events were classified based upon three distinct outcomes. Event group A, where the peak depth recorded occurred at the top of the reach before the peak depth was recorded at the bottom of the reach. Event Group B, where the peak depth occurred at the same time at both the top and bottom of the reach. Event group C, where the bottom of the reach peaked before the top of the reach.

Boxplots of the variables listed in

Table 2-1 were created for both antecedent conditions and variables recorded during the event to compare the three event group types. Kruskal Wallis H tests were used to determine if any variables listed in

Table 2-1 were statistically different between each group (Ostertagova et al., 2014) and the Wilcoxon post hoc test was used to determine which of the three groups were statistically different (Woolson, 2007). All statistical analysis was undertaken using RStudio (1.3.1093) to determine any significant differences between the three classifications.

### 2.3.3 Flow Rates

Flow rate data were collected from both tributaries as a control to determine the time taken during low flows for water to discharge through the reach. This was compared with the peak timings recorded during the events selected. The relative discharge of both tributaries was measured in the field using slug-injection salt dilution gauging (Moore, 2005). Flow through the v-notch weir was assessed using the bucket and stopwatch method, as this method is well adapted for small flows (Salazar et al., 1994). The bucket test was completed for three of the four V-notch weirs (the v-notch at the top of T3 had failed and was therefore not measured). The bucket was placed directly below each V-notch to capture any water flowing through it. The time taken for the bucket to fill to a defined depth was recorded. This was repeated 3 times at each v-notch to allow an average to be calculated. Flow rates were then calculated using

Flow (l/s) = Volume of bucket (litres) /time to fill (seconds).

### 2.3.4Trail Camera analysis

Visual analysis of trail cameras which were installed on the site was undertaken and images were compared for each of the event groups (A, B and C) preceding the rainfall event and 24 hours after the peak depth was recorded for the event. This visual analysis was used to support the findings collected. Trail cameras recorded data every 15 minutes.

## 2.4 Community questionnaire

In order to ascertain the target community's understanding and acceptance of NFM, a questionnaire, using a combination of both quantitative and qualitative methods was deemed most appropriate due to the nature of the data and time constraints available to the project. Research undertaken by Bark et al. (2021), looked to establish the views of stakeholders on NFM through an online mixed method questionnaire which used both quantitative and qualitative methods. A similar methodology was adopted for this study. However, Bark et al. (2021) did not explore the views of the public or the community strengthening the rationale for this survey.

The questionnaire utilised both 'open' and 'closed' questions to ascertain the opinions of the local community. The use of 'closed' questions allowed participants to answer questions quickly in addition to enabling statistical analysis of the results using Fishers test (Odén and Wedel, 1975). Open questions allowed for a qualitative approach, facilitating the elaboration of participant's opinions without risk of researcher bias (Philip, 1998). Many examples asked the participants 'Please explain why you feel this way.' These questions had no word limit, allowing participants to fully explain their answers. This was deemed to be the most effective measure to gather contextualised answers with examples. In total, the questionnaire included 76 questions spanning 31 categories (Appendix A). Of the 76 questions asked, 38 questions were open questions. Although follow up semi-structured interviews, which would give the participants further opportunities to provide qualitative responses (Philip, 1998), may have been useful, the current survey methodology was deemed most appropriate for this research due to the ongoing COVID-19 pandemic, allowing the gathering of data without increased social contact.

### 2.4.1 Questionnaire design

A total of 31 questions, covering previous flooding knowledge, effectiveness of NFM as a flood reduction strategy, secondary impacts of NFM (environmental, personal and community) and the role of organisations in NFM projects were presented (See

Appendix A). These questions were devised to understand the impact that NFM can have on local communities.

In the first section of the questionnaire, questions 1 to 5, were focused on gathering previous flood knowledge of the participants. Question 6 to 7 and 9 to 13 were used to gather their opinions of NFM's flood reduction capabilities. The next section, including questions 8 and 14 to 20, gathered knowledge and opinions of the secondary benefits associated with NFM. Questions 20 to 23 were focused on gathering participants' opinions on the role of different organisations delivering NFM. The final section gathered demographic data including age, gender, occupation, education level and area in which they resided. This information was designed to provide further background to participant's opinions.

Specific topics were selected to elicit desire responses from the participants. Statements covered there topics included flood management, NFM and reported knowledge of NFM and flood management. It was important to understand the feelings of participants towards these topics to develop a better understanding of how much the community is impacted. This allowed for more detailed understanding of the beliefs of the community towards specific topics and how these topics may impact their feelings towards NFM. A similar approach was undertaken by Bark et al. (2021) which successfully captured to capture the beliefs and opinions of stakeholder involved in NFM. Trust in stakeholders was also deemed an important area for further research as previous studies have shown trust of communities in flood projects can be depended on a community's relationship with stakeholders (Mehring et al., 2018).

The questionnaire collected data in the form of Likert, multiple choice, matrix and ranked scale questions (Cloke et al., 2004, Flowerdew & Martin, 2005). Participants had the option of further elaborating by completing open box questions. The Likert question scale was chosen to best represent attitudes (McLafferty, 2003).

Multiple choice questions were also used to best represent binary questions in relation to NFM (McLafferty, 2003) Most multiple-choice questions were used as an initial introductory question to route participants to other questions. A matrix style question was employed to capture answers whereby participants could provide several

responses to the same question (McGuirk and O'Neill, 2016). Within this survey, participants were asked to select out of a list of five stakeholders who they felt should be providing the eight different roles to deliver an NFM project (Appendix A).The ranked scale question was deemed the most appropriate style to represent the question that required participants to order answers based on preference (McLafferty, 2003). For this survey, participants were asked to rank secondary benefits of NFM in order of preference (There were 10 secondary benefits listed in this question).

An online questionnaire was chosen as the most appropriate method to collect the Calderdale community's opinions in relation to NFM (Bird, 2009., McLafferty, 2003). The online survey tool 'Online Surveys' was used to build the questionnaire. An online survey was selected as an effective method of data collection for this study as it allowed the greatest distribution of the survey through online websites to reach as many residents in Calderdale as possible. It was also the most appropriate and safe method to obtain respondents during the COVID-19 pandemic, limiting the risks to participants and the researcher. After launching the survey, it was noted that some participants were unable to submit their answers to some of the questions. This was due to the online survey website incorrectly suggesting that there was an error with the answer choice. For this reason, every question was changed from 'Required' to 'Optional' to combat the issues that occurred. The questionnaire was hosted by the University of Leeds and published online between the dates of the 7$^{th}$ of June and 9$^{th}$ of July 2021.

During the designing of the survey, a test study was launched. This was to test the routing of the survey and the phrasing and sequencing of the questionnaire (McLafferty, 2003). As a result of the pilot study feedback, small changes were made to improve the questionnaire (See Appendix A).

### 2.4.2Sampling procedure

The survey used self-selective sampling procedures to recruit participants. Similar sampling procedures have been used by researchers seeking to gather the opinions on NFM including research by Bark et al., (2021) which recruited participants using professional networks. Participants were recruited using online resources as well as

professional organisations such as water@leeds. Snowball sampling (Bark et al., 2021) was also encouraged via participants sharing the questionnaire with others through circulating the online link. This was to help overall engagement with the survey from participants who do not regularly use online websites as well as increase the variation of people who accessed the survey.

Online advertising using Facebook was used to target established community groups within the Calderdale area. Community pages were researched for suitability of advertisement such as how active the pages were, how many members were within the groups, if they were public or private and if they had regular engagement on posts made within the groups. Key words such as: ‘Calderdale’, ‘Hebden Bridge’, ‘Flooding’ and ‘Calder’ were used to identify potential groups. Previous research (Taylor et al., 2012) has used similar platforms to engage participants, indicating the relevance of such methods. Administrators of each group were contacted to gain permission to post the advertisement and link to the online questionnaire. In total nine pages were used to advertise the questionnaire (Table 2-2). During the period whilst the survey was active, four different posts were made to each group to advertise.

Table 2-2 - Social media groups and types used for survey distribution

| Online social media platform | Group Name |
|---|---|
| Facebook | Hebden Bridge |
| | Todmorden flood group |
| | Calderdale communities |
| | This is Todmorden |
| | Calder Valley Flood Support |
| | Mytholmroyd |
| | Tod Chat & That |
| | Hebden Bridge Offcumdens |
| | Mytholmroyd Life |
| Twitter | Personal Profile |
| News and radio (received no response) | Hebden Bridge Times |
| | Examiner |
| | Radio Aire |
| | Telegraph and Argus |
| | Todmorden News |
| | Yorkshire Post |
| Calderdale Flood Partnership | Newsletter posted on the eyeoncalderdale.com website |

In addition to social media platforms, STF advertised the survey on their personal Facebook page to other community groups. This provided additional coverage of the survey to those already engaged in the subject area to be reached.

In addition to Facebook, Twitter was also used as an online platform to increase the visibility of the survey. Several posts were made using the researcher's personal Twitter page to advertise the survey. Different organisation and individuals (e.g. the National Trust, the Environment Agency West Yorkshire, Calderdale Council and many others) where tagged within the twitter posts. Hashtags, such as 'flooding', 'NFM' and 'Calderdale' were also used to distribute the post to a wide variety of individuals. This facilitated access to a range of participants from a variety of backgrounds. Several posts were made throughout the month the survey was active. The posts gained between 700 and 10,000 views per post with many directed to the survey.

Two individual posts were made on LinkedIn using the researcher's personal profile. The post used several 'tags' such as 'Calderdale', 'Research', 'Questionnaire' and 'flooding'. Institutions such as Leeds University and the Chartered Institute of Water and Environmental Management (CIWEM) were also tagged in these posts. The president of CIWEM shared one of these posts. An average of around 170 views per post was achieved.

### 2.4.3Statistical analysis of questionnaire data

Results were analysed using descriptive and inferential statistical methods. Data collected from 'closed' questions was analysed using descriptive statistics by creating percentages of responses to each category (Blalock, 1979). Data collected from open questions was analysed using thematic analysis technique, 'coding' responses dependent upon their themes (Gibbs, 2007). These themes were then analysed using descriptive statistics.

Fisher's exact test (Kim, 2017) was selected as the data consisted of distinct quantitative data (Zibran, 2007). This methodology was adopted for this study and variables tested were age, gender, occupation, town residing in, previous flood and NFM knowledge, if they had been previously flooded and if they had accessed flood action. SPSS software, version 26 was used to analyse all questionnaire data, and a significance level of 0.05 used to signify where a statistically significant relationship existed.

# 3 Results

## 3.1 Hydrological analysis of leaky wood dams

Of the nineteen events selected, nine were categorised as group A (events in which the flood peak was slowed from the top to the bottom of the reach), eight as group B (events in which the flood peak was recorded at the same time at the top and bottom of the reach) and four as group C (the events flood peak was recorded at the bottom of the reach before the top of the reach). The difference in peak timings record in group A and C events are recorded in Table 3-1.

Table 3-1 - The recorded time difference in flood peaks for group A and C events

| Group | Date of events peak depth (d/m/y) | Difference in peak time (h:m) |
|---|---|---|
| A | 12/03/2019 | 02:10 |
| | 16/03/2019 | 01:06 |
| | 09/08/2019 | 00:15 |
| | 15/02/2019 | 02:15 |
| | 24/07/2019 | 00:15 |
| | 28/07/2019 | 00:34 |
| | 11/01/2020 | 00:15 |
| | 19/07/2019 | 00:15 |
| | 25/08/2020 | 00:15 |
| C | 07/11/2019 | -00:45 |
| | 11/11/2019 | -00:45 |
| | 10/08/2019 | -01:15 |
| | 21/07/2019 | -00:45 |

Hydrographs were created for all group A events and are seen in Appendix B. Two event hydrographs were chosen and these are presented in Figure 3-1 and Figure 3-2**Error! Reference source not found.**. The hydrographs were visually analysed. It was noted that for five of these events peaks were delayed for no more than 15

minutes. Since the data collection was set to a 15 minute interval, there was only a difference of one data point between the peaks recorded at the top and the bottom of the tributary. The hydrographs for group A events show that at the top of the reach there is mostly a distinctive peak. Whereas, the hydrographs that show the depth at the bottom of the reach had a more rounded peak which could suggest that the leaky dams are having an impact on the rate of discharge at the bottom of the tributary.

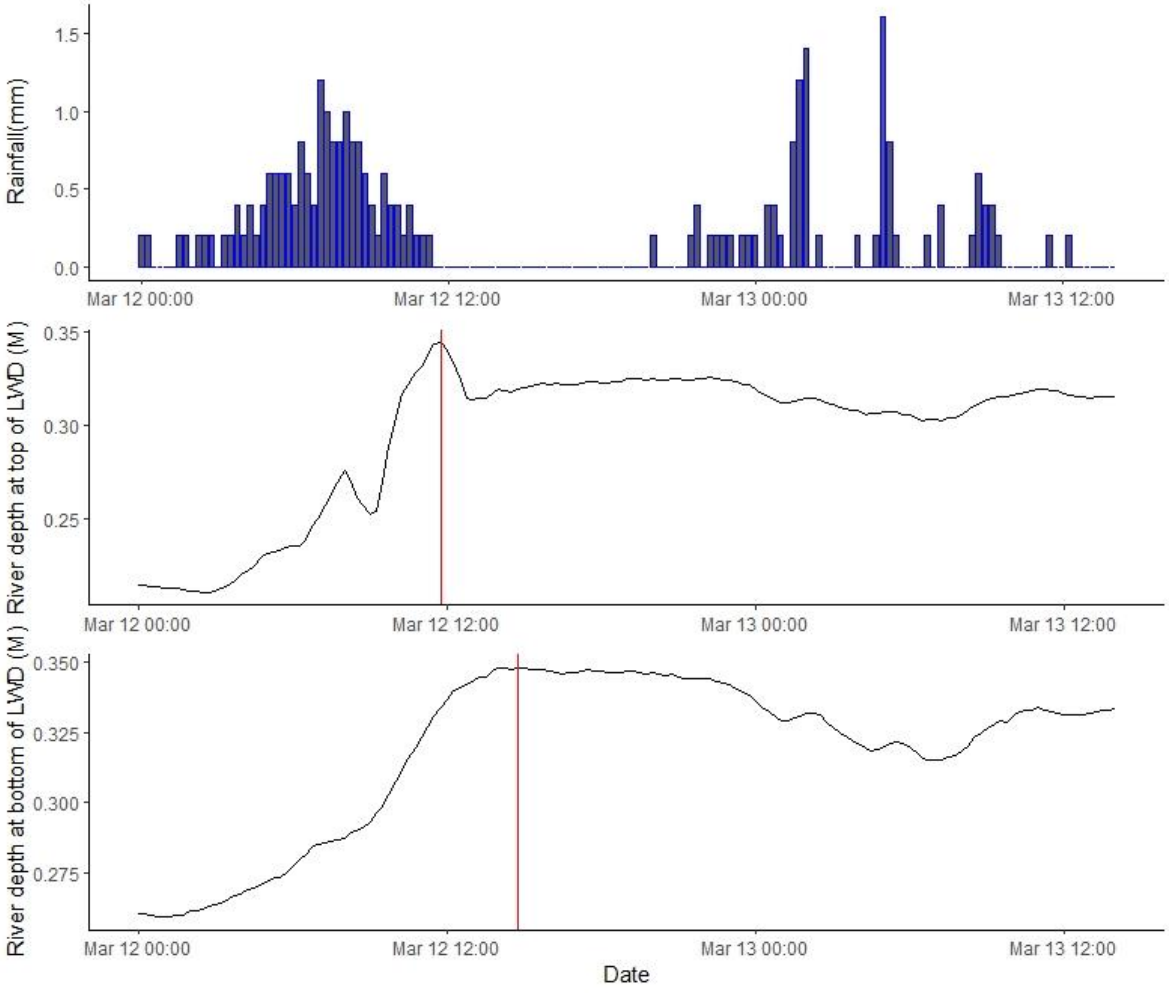


Figure 3-1 - A hydrograph of rainfall and river depth record during the 12th March 2019 group A event. The red line indicates the peak of the hydrograph.

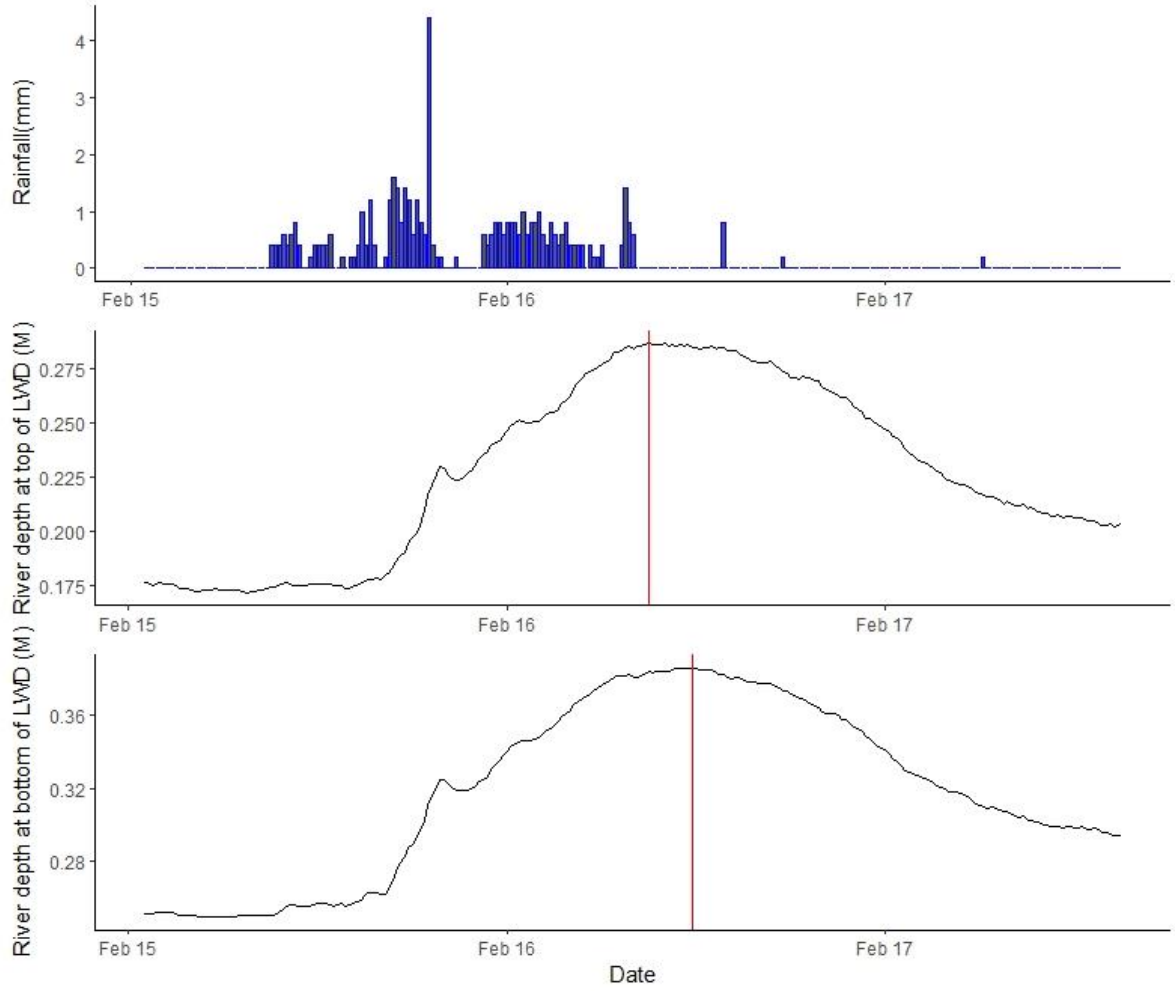


Figure 3-2 - A hydrograph of rainfall and river depth record during the 15th February 2020 group A event. The red line indicates the peak of the hydrograph.

Hydrographs were visually analysed for group C events and are presented in Figure 3-3 and Table 3-2 –The time and date the peak depth (m) recorded at the top and bottom of the leaky wood dam during the 7th November 2019 group C event with a rolling average window of 3 and 5. The peak depth recorded is highlighted in red.. It was noted that for group C hydrographs peak depths were typically less distinct at both the top and bottom of the reach. Upon analysing the data collected and the rolling window data, it was noted that peak depth was recorded at several occurrences. The difference within the peak depths record were noted as being as less than 1mm in some instances.

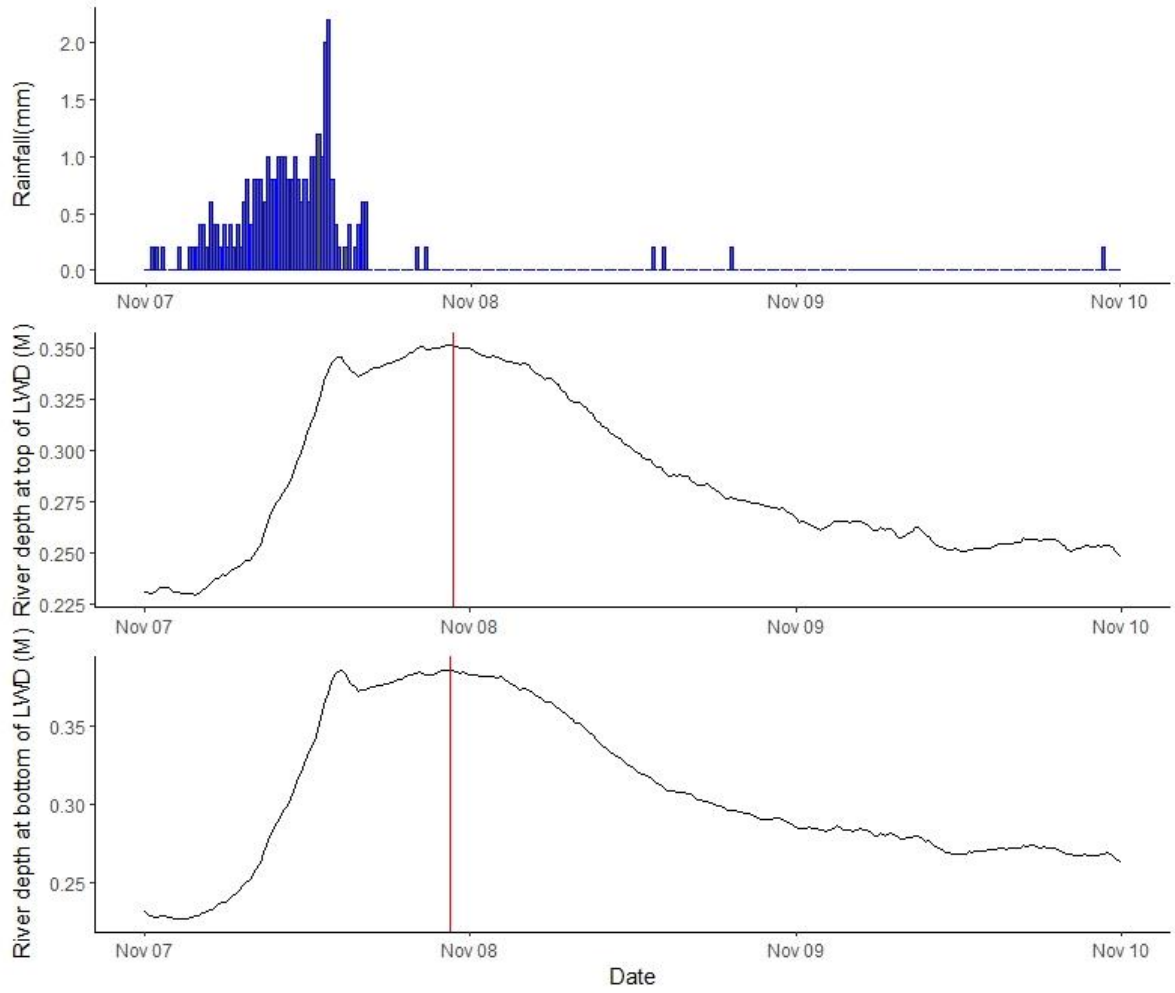


Figure 3-3 - A hydrograph of rainfall and river depth record during the 7th November 2019 group C event. The red line indicates the peak of the hydrograph.

Table 3-2 –The time and date the peak depth (m) recorded at the top and bottom of the leaky wood dam during the 7th November 2019 group C event with a rolling average window of 3 and 5. The peak depth recorded is highlighted in red.

| Date and Time (D/M/Y H:M) | Top of LWD (m) | Top of LWD Rolling average 3 (m) | Top of LWD Rolling average 5 (m) | Bottom of LWD (m) | Bottom of LWD Rolling average 3 (m) | Bottom of LWD Rolling average 5 (m) |
|---|---|---|---|---|---|---|
| 7/11/19 14:30 | 0.347 | 0.3456667 | 0.3456 | 0.3921509 | 0.3863744 | 0.3855657 |
| 7/11/19 20:00 | 0.353 | 0.503333 | 0.3494 | 0.3847095 | 0.3844037 | 0.3838328 |
| 7/11/19 22:15 | 0.350 | 0.3516667 | 0.3514 | 0.3860347 | 0.3875297 | 0.3854434 |
| 7/11/19 22:30 | 0.353 | 0.3510000 | 0.3514 | 0.3876656 | 0.3851512 | 0.3860958 |
| 7/11/19 22:45 | 0.350 | 0.3516667 | 0.3516 | 0.3817533 | 0.3851852 | 0.3857696 |
| 7/11/19 23:00 | 0.352 | 0.3516667 | 0.3512 | 0.3861366 | 0.3850493 | 0.3846279 |
| 7/11/19 23:15 | 0.353 | 0.3510000 | 0.3502 | 0.3872579 | 0.3845736 | 0.3837717 |

Results from the Kruskal Wallis H test used to determine any statistically significant differences between event groupings and rainfall/ event characteristics are outlined in Table 3-3. Two variables were identified as having significant differences between groups, peak rainfall to peak depth (p= 0.038) and start of rainfall to start of event (p =0.006). Post hoc tests were used to determine which different groups were statistically different for each of the variables. The post hoc Wilcoxon test indicated that for Peak rainfall to peak depth Events B and C were significantly different (p= 0.033) and for 'Start of rainfall to start in event' events A and C were significantly different (p= 0.002; Appendix B). The significant ones were also indicated on the boxplots in Figure 3-3.

Table 3-3 - Results from Kruskal Wallis H statistical test of rainfall and flood characteristics and event grouping. Blue cells highlight significant results ($p \leq 0.05$).

| Variable name | Kruskal Wallis H Result (P) |
|---|---|
| Rainfall duration(h) | 0.701 |
| Total rainfall(mm) | 0.559 |
| Mean (mm/h) | 0.061 |
| Peak rainfall in 15-minute interval (h:m) | 0.658 |
| Rainfall three days antecedent (mm) | 0.350 |
| Rainfall one day antecedent (mm) | 0.161 |
| Time between start and peak (h:m) | 0.228 |
| Peak depth (mm) | 0.776 |
| Difference in peak depth and depth 24 hours event (mm) | 0.093 |
| Peak rainfall time to peak depth (h:m) | 0.038 |
| Difference in peak depth and initial depth (mm) | 0.464 |
| Difference in initial depth and depth 24 hours after event (mm) | 0.112 |
| Time taken between start of rainfall and start of event (h:m) | 0.006 |

### 3.1.1River response to rainfall events

Boxplots highlight variables associated with the rainfall recorded such as mean rainfall per hour, rainfall duration, total rainfall during the event and peak rainfall which were recorded within each of the event group types. Box plots were created to show differences in the antecedent conditions such as rainfall three days antecedent and rainfall one day antecedent, between the three event groups. Whilst no groups were deemed to be statistically different, the variable ‘mean rainfall per hour’ was close to being statistically significant (p= 0.061).

### 3.1.2Hydrograph Characteristics

Box plots were created to show differences in the hydrograph response between the three event groups (Figure 3-4). Using the Kruskal Wallis H statistical test it was deemed that plots F and I contained groups which were statistically significant. The Wilcoxon test was used to determine which groups were statistically different from each other. For plot F the variable ‘time taken between peak rainfall and peak depth’, groups B and C were statistically different from each other (p= 0.033). For plot I the variable ‘difference between start of rainfall and start of event’ groups A and C were deemed to be statistically different (p= 0.002).

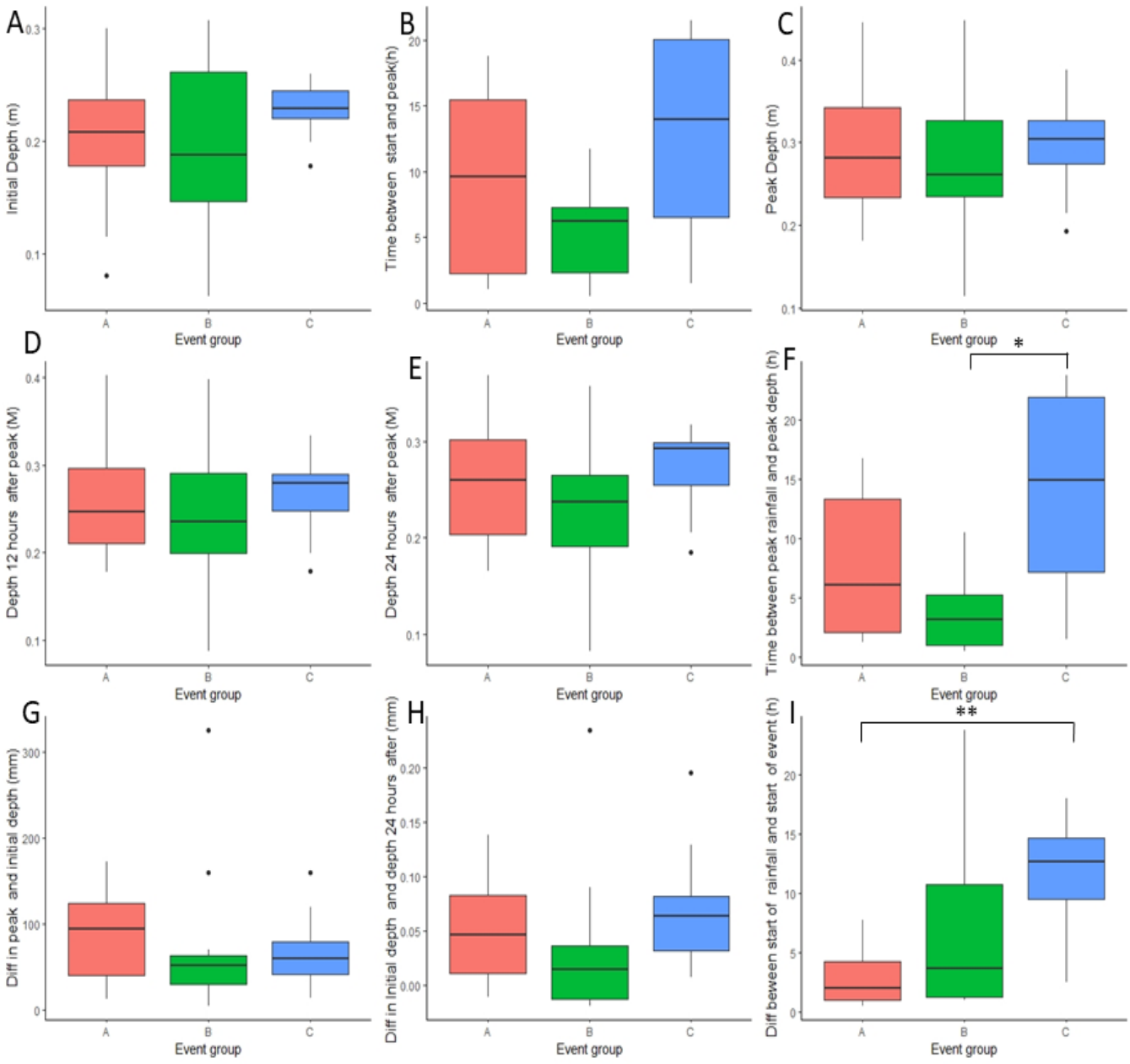


Figure 3-4 - Boxplots of recorded variables with statistically different groups highlighted as *= AB and **=BC. A: Initial depth, B: Time between start and peak of event, C: Peak depth, D: Depth 12 hours after peak, E: Depth 24 hours after peak, F: Time between peak rainfall and peak depth, G: Difference in peak and initial depth, H: Difference in initial depth and depth 24 hours after, I: Difference between start of rainfall and start of event

### 3.1.3 Trail Camera Analysis

Trail camera footage from a Group A event, a Group B event and a Group C event was reviewed and revealed notable differences between initial conditions of the instream features and the subsequent conditions after the event occurred (Appendix D). Preceding the Group A event there was visually a low amount of water in the tributary and the leaky wood dam did not have a lot of water behind it. Preceding the Group B event there was more water in the tributary than before the Group A event and the dam was already about half full. Preceding the Group C event there was more water in the tributary than before the Group B event and the dam was already full. 24 hours after the peak depth was recorded the Group A event dam was almost full, the Group B event dam was full, and the Group C event dam was over-topping. Therefore, the NFM measures worked effectively when there was significantly less water behind the leaky wood dam before the rainfall event occurred.

### 3.1.4Flow Rates of Tributaries

On average, the time taken for the salt solution to travel through the reach of T2 was 12 minutes 10 second.

Table 3-4 - Time taken for salt dilution to travel down T2

| Date | Tributary name | Tributary type | Time taken to travel through the reach (m:s) |
|---|---|---|---|
| 17/5/2021 | T2 | NFM | 12:10 |
| 9/6/2021 | T2 | NFM | 13:10 |
| 8/7/2021 | T2 | NFM | 11:10 |

## 3.2 Community questionnaire analysis

Upon closing the survey, 51 participants had completed the questionnaire with 834 participants initially clicking onto the survey link, giving a 0.06% completion rate. To increase completion rate, an initial screening question to highlight those completing the survey should work or live in Calderdale. This was employed within Bark et al. (2021) Responses to questions asked about participant's previous knowledge and previous experiences are presented in Table 3-5 and Table 3-6. 61 pages of open-ended responses were gathered and categorised and are presented in Appendix C.

In general, it was found that participants reported they were knowledgeable about flood management and NFM (63% above average or very knowledgeable), the community supported NFM as a flood reduction tool (90% agree or completely agree) and several personal and community impacts were noted. Responses to the impacts of NFM were categorised into NFM's effectiveness, environmental impacts, personal impacts, community impacts and delivering NFM. These were analysed against the personal attributes of the participants.

Table 3-5 - Summary of questionnaire respondents' answers of rated knowledge. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered 'N/A'

| Statement | Very knowledgeable % | Above average % | Average % | Below average % | Very little knowledge % | Total Response (number of participants) |
|---|---|---|---|---|---|---|
| How would you rate your current understanding of the impact of flooding? | 15.7 | 47.1 | 37.3 | 0 | 0 | 51 |
| How would you rate your current understanding of flood management? | 5.9 | 47.1 | 33.3 | 13.7 | 0 | 51 |
| How knowledgeable do you feel you are about flood management in your area? | 13.7 | 39.2 | 35.3 | 11.8 | 0 | 51 |
| How knowledgeable you are with regards to natural flood management? | 6.5 | 43.5 | 41.3 | 6.5 | 2.2 | 46 |

| | | | | | | |
|---|---|---|---|---|---|---|
| How would you rate your awareness of NFM projects that are happening in Calderdale? | 9.8 | 39.2 | 23.5 | 17.6 | 9.8 | 51 |

Table 3-6 - Summary of questionnaire respondents' answers of previous experiences. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered 'N/A'

| Statement | Yes % | No % | Not sure % | Total of response (number of participants) |
|---|---|---|---|---|
| Have you been personally affected by flooding within your area? | 54.9 | 45.1 | 0 | 51 |
| Have you ever accessed any form of flood action or prevention within Calderdale? (for example, you may have joined a online flood group) | 52.9 | 43.1 | 3.9 | 51 |
| Have you heard of the term 'Natural Flood Management (NFM)' before?' | 82.4 | 9.8 | 7.8 | 51 |
| Have you ever volunteered for organisations and/or charities that are delivering natural flood management? | 19.6 | 76.5 | 3.9 | 51 |

The number of people who volunteered for each organisation was six for Treesponsibility (50%), seven for STF (58.3%), one for Calder Future (8.3%), one for Wildlife Trust (8.3%), one for Moors for the Future (8.3%), four for the National Trust (33.3%) and three for others (25%). People felt they gained a good experience (100%) and learnt about NFM (50%) and their local area (50%) as a result of their volunteering. 54.5% of respondent felt their mental health had been positively impacted. 66.7% of

those who had volunteered felt they had gained a greater connection to their local area which allowed them to appreciate the environment more (33.3%). Out of those who had volunteered 66.7% actively visited NFM interventions within their free time.

Participants were asked to determine the effectiveness of NFM through a variety of statements presented in Table 3-7

Table 3-7 -Summary of respondents' answers on the effectiveness of NFM. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered 'N/A'

| Statement | Completely agree % | Agree % | Neither agree nor disagree % | Disagree % | Completely disagree % | Total Reponses (number of participants) |
|---|---|---|---|---|---|---|
| Do you feel NFM is a flood management tool you support? | 70.6 | 19.6 | 5.9 | 2 | 2 | 51 |
| I believe NFM has reduced flood risk in Calderdale'. | 12 | 40 | 42 | 2 | 4 | 50 |
| I believe that NFM measures are an effective tool at reducing flood risk. | 36 | 44 | 12 | 6 | 2 | 50 |
| I feel NFM should be used with several other measures to reduce flood risk. | 48 | 40 | 10 | 0 | 2 | 50 |

Respondents were given the opportunity to express their opinions using the open-ended questions associated with the questions listed in Participants were asked to determine the effectiveness of NFM through a variety of statements presented in Table 3-7

Table 3-7When asked if to explain their opinions of NFM, an overwhelming number of responses stated their support of NFM (88%) with one respondent stating “Hebden water has not reacted as much as it has in previous similar rainfall events. I'm putting this down to the hundreds of leaky Woody debris dams and attenuation ponds in hardcastle crags”. 20% felt NFM would reduce the need for hard engineering or would make hard engineered defences more effective. Some felt NFM made sense (16%), reduced flooding (31%) and that NFM should be used with several other measures (16%). 23.1% felt that more NFM projects were required in Calderdale although others stated that they felt they didn’t have enough knowledge to have an opinion (15.4%) and 15.4% felt that existing NFM projects required further time to establish an effect. When asked if they felt NFM had reduced flood risk in Calderdale, 30% felt that it was too early to say if NFM was effective with one respondent stating “I think it WILL, but whether it has yet on any major scale is too early to say”. 26.2% felt that they didn’t have enough knowledge or evidence to have an opinion. Conversely, 26.2% stated that they had personally seen NFM working. The majority (63.2%) agreed that NFM should be used with several other measures to reduce flood risk but 10.5% contradicted this and felt that NFM should be used exclusively. Other comments related to land management (21.1%), which in itself is a form of NFM, were collected and one respondent stated support for river dredging.

Table 3-8 - Summary of respondents’ answers on the environmental impacts of NFM. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered ‘N/A’

| Statement | Completely agree % | Agree % | Neither agree nor disagree % | Disagree % | Completely disagree % | Total Response (number of participants) |
|---|---|---|---|---|---|---|
| I believe NFM is improving my local environment. (e.g. nature, ecosystems and wildlife). | 40 | 38 | 16 | 0 | 6 | 50 |

Open-ended responses related to the environmental impacts of NFM stated that they felt NFM improves their local environment (75%) with one respondent stating “There are more trees, properly managed, less soul erosion, encouragement of natural wild flowers, inviting insects, birds, small mammals etc”. Others (25%) responded by stating that more time or more NFM implementation would be required to form an opinion. Participants were asked if they knew of any additional effect NFM could have other than flood reduction. Half of the participants selected yes (51%) and they were asked to list some of these effects using an open-ended question. 48% of participants listed biodiversity, 28% said tree planting (which is in itself is not a benefit but can provide benefits), 28% said habitat creation and 28% said wildlife.

Table 3-9 - Summary of questionnaire respondents' answers on the personal impacts of NFM. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered 'N/A'

| Statement | Completely agree % | Agree % | Neither agree nor disagree % | Disagree % | Completely disagree % | Total Responses (number of participants) |
|---|---|---|---|---|---|---|
| I believe I have personally benefited from the implementation of NFM. | 8 | 22 | 46 | 14 | 10 | 50 |
| I believe that developing my awareness around NFM has had an impact on my mental health. | 7.8 | 13.7 | 52.9 | 13.7 | 11.8 | 51 |
| I believe NFM has made me more resilient to the impact of flooding. | 2 | 15.7 | 60.8 | 7.8 | 9.8 | 51 |
| I believe NFM has made me more resilient in recovering from flooding. | 0 | 9.8 | 68.6 | 5.9 | 7.8 | 51 |
| I wish to be more involved with the implementation of NFM (e.g. planning, designing and implementing). | 12 | 18 | 44 | 20 | 6 | 50 |

Participants were asked state the impact NFM had on the community through a variety of statements presented in Table 3-10.

Table 3-10 - Summary of questionnaire respondents' answers on the community impacts of NFM. % of respondents listed. Not all rows will sum to 100% as some respondent chose not to answer and/or answered 'N/A'

| Statement | Completely agree % | Agree % | Neither agree nor disagree % | Disagree % | Completely disagree % | Total Response (number of participants) |
|---|---|---|---|---|---|---|
| I believe my community has benefited from the implementation of NFM' (e.g. community spirit, improving wellbeing, community engagement). | 19.6 | 39.2 | 27.5 | 7.8 | 5.9 | 51 |
| I believe NFM has made my community more resilient to the impact of flooding. | 9.8 | 43.1 | 35.3 | 5.9 | 5.9 | 51 |
| I believe NFM has made my community more resilient in recovering from flooding | 7.8 | 25.5 | 51 | 7.8 | 5.9 | 51 |

Participants left open-ended responses in relation to what they felt were the community impacts of the implementation of NFM. 26.7% felt the community had positively benefited from the implementation of NFM with one response stating “It is a long process but it has started and is showing encouraging signs.” Whereas 33.3% felt that they didn’t know enough about the community impact of NFM and a further 20% felt that NFM was not yet effective enough to have an impact on the local community. When asked if they felt NFM had made the community more resilient to the impact of flooding 33.3% felt they seen a positive impact but 22.2% felt they were unaware of these impacts. Similarly, when asked if they felt NFM had impacted the communities’ ability to recover from flooding, 28.6% stated they were not aware of any impacts and a further 42.9% stated that they had not been flooded so therefore felt no impact.

Responses to participants’ ranking of the secondary benefits associated with NFM in order of importance are outlined in Table 3-11 below. Mean values of the rankings indicated that reduced flood risk was the most important NFM benefit, followed by habitat creation and increased biodiversity.

Table 3-11 - Summary table of mean values collected when participants were asked to rank the environmental benefits in order of 1 to 10, with 1 being most important and 10 being least important.

| Potential benefits | Mean value | Ranked |
|---|---|---|
| Reduced flood risk | 1.71 | 1 |
| Habitat creation | 3.98 | 2 |
| Increased biodiversity | 4.54 | 3 |
| Reduced erosion | 4.69 | 4 |
| Resilient ecosystem | 4.83 | 5 |
| Improved water quality | 5.33 | 6 |
| Sediment management | 5.89 | 7 |
| Community spirit | 6.71 | 8 |
| Carbon sequestration | 6.98 | 9 |
| Greater connection to nature | 7.13 | 10 |

## 3.2.1Personal attributes and responses to NFM

Respondents' opinions of the impacts of NFM were analysed according to participants' gender, previous flood knowledge, flood history and access to flood action.

### 3.2.1.1 Demographic analysis

Results from the Fishers test of demographic variables including age, gender, occupation and town indicated that age and town of residence had no significant determination on the respondents' responses to the questionnaire ($p>0.05$). Occupation and gender of respondents were determined to have an effect on the respondents' opinions. Participants whose occupations were described as environmental (public and private), public sector (government), private sector (other), academic and other believed that NFM had reduced flood risk in Calderdale ($p = 0.013$). These occupations also believed that NFM had made the community more resilient to the impact of flooding ($p= 0.032$). Participants whose occupation was described as academic also had confidence in charities, local government, private companies and government agencies to manage NFM within Calderdale ($p= 0.034$). Male participants were more likely to volunteer to deliver NFM ($p= 0.030$) and were more likely to agree that the implementation of NFM had benefited the community ($p= 0.010$) and made the community were more resilient to the impact of flooding ($p= 0.009$).

### 3.2.1.2 Respondents' previous knowledge of flood management and NFM in their area

Respondents who had rated themselves as being very knowledgeable/ above average about flood management in their area were also likely to have heard of NFM before ($p= 0.036$), rated themselves as very knowledgeable/above average about NFM ($p =0.000$), and rated themselves as having the most awareness of NFM projects occurring in Calderdale ($p= 0.000$). Those who rated their local flood knowledge as very knowledgeable, were more likely to be sceptical that NFM had reduced flood risk

in Calderdale (p= 0.037) but those who rated themselves as above average were more likely to agree that NFM had reduced flood risk in Calderdale (p= 0.037).

Secondary benefits were also noted by those who rated their local flood knowledge as above average as these respondents felt connected to their local environment when they volunteered to implement NFM (p= 0.001) and also felt that volunteering had impacted their mental health (p= 0.001). Those who reported an above average knowledge of flood management in their areas also reported that they had personally benefitted (p=0.005), the community had benefited (p= 0.010) from NFM, that developing their awareness of NFM had impacted their mental health (p=0.006) and that NFM had made them more resilient to the impacts of flooding (p= 0.037).

Participants who rated themselves as very knowledgeable or above average regarding NFM had also previously accessed flood action or prevention in Calderdale (p= 0.020). They also rated their awareness of NFM projects in Calderdale as very knowledgeable or above average (p= 0.000). Participants who rated themselves as very knowledgeable about NFM would wish to be more involved with the implementation of NFM (p= 0.013).

#### 3.2.1.3 Access to flood action and support and previous flood history

Participants who had previously been affected by flooding had also accessed a form a flood action or prevention within Calderdale (p= 0.036). Those participants who had previously accessed a form of flood action or prevention in Calderdale considered themselves as being very knowledgeable/above average about NFM (p= 0.020) and had previously volunteered with an organisation and/or charities delivering NFM (p= 0.031). Participants who had accessed any form of flood action were more likely to completely agree that NFM measures should be used with several other flood management measures, whereas those who had not accessed a form of flood prevention were more likely to agree or neither agree nor disagree (p= 0.017) that NFM should be used with other flood management measures.

### 3.2.2 Management of NFM community projects

When asked if participants had confidence in the charities, local government, private companies and government agencies to manage NFM within Calderdale, 3.9% completely agreed, 27.5% agreed, 31.4% neither agreed nor disagreed, 31.4% Disagreed and 5.9% completely disagreed. Open-ended responses associated with the question showed that 45.9% of respondents felt the government and local councils should have more responsibility for managing NFM. Other respondents felt that more NFM implementation needs to be done (25%). Charities were more trusted to undertake NFM (20.8%). Some felt that the Government should place some restrictions in land management practises that affect flood risk, whilst also creating subsides for landowners to implement NFM on their land (20.8%). Further open-ended responses stated that NFM currently receives a lack of funding (20.8%).

The community were asked which stakeholders they felt were best placed to undertake the different roles within an NFM community project. These results are presented in Figure 3-5. Overall, the community selected a multi-organisational approach to NFM projects with all of the five stakeholders selected for all the eight roles presented. However, the community did have some preferences for stakeholders that should be involved with some roles. Figure 3-5 shows that the community favoured government agencies in the roles of planning and implementing, funding, and monitoring and collecting data of NFM (plots A, C and F); Local government were favoured for talking/getting in touch with landowners about the introduction of NFM on their property, upkeep of MFM measures and providing education on NFM measures (plots D, G and H); Local community groups were favoured in the roles of designing of NFM, implementing NFM and providing education on NFM measures (plots B, E and H). Private Water companies and national charities were not favoured for any of the roles.

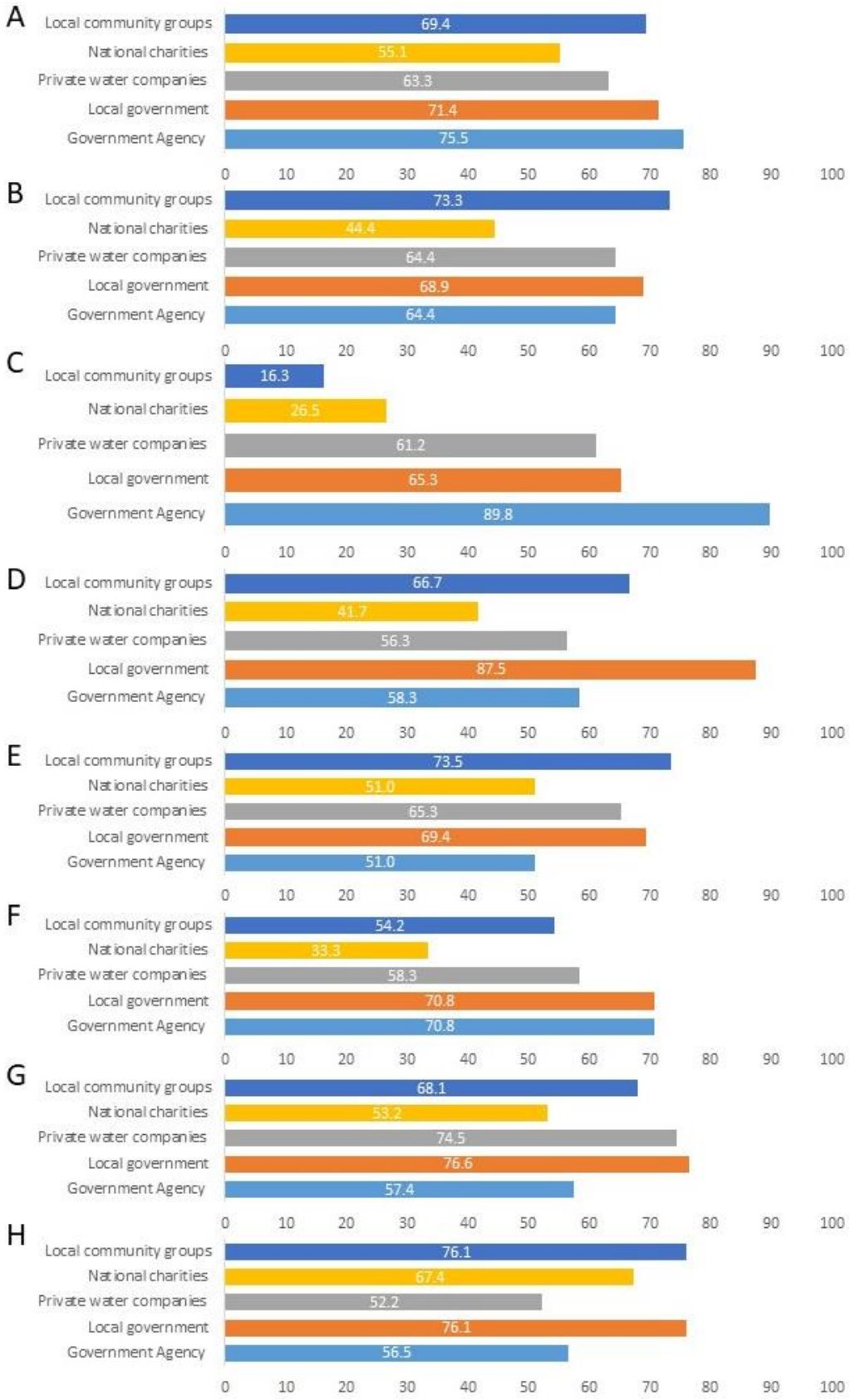


Figure 3-5 - Community opinions on which stakeholders are best placed to undertake roles within an NFM project (%) A: Planning the implementation of NFM, B: Designing

of NFM, C: Funding of NFM, D: Talking/getting in contact with landowners about the introduction of NFM on their property, E: Implementing NFM in the catchment, F: Monitoring and collecting data from NFM measures, G: Upkeep of NFM measures, H: Providing education on NFM measures.

# 4 Discussion

This research has evaluated the impact of one community NFM project on the Calderdale community. Hydrological data collected from interventions managed by a community NFM project and local community's feelings about NFM were analysed. The main findings of this analysis are discussed in relation to other relevant research findings below.

## 4.1 Community collected hydrological data

As previously stated, evidencing the effectiveness of NFM through modelling is complex (Metcalf et al, 2017) and the lack of evidence around the effectiveness of NFM in reducing flood risk reduces the adoption of NFM (Wingfield et al., 2019; Spray et al., 2009) and therefore the collection and analysis of in-field data is vital. Previous modelling of leaky dams by Thomas and Nisbet (2012) indicated that downstream flood peaks could be slowed by 15 mins. In-field research by Black et al. (2021) showed that leaky wood dams, riparian planting and tree planting combined increased lag times throughout a catchment by up to 7.3 hours, but that the effectiveness of the leaky wood dams could not be isolated from the other measures. This research has also established that during some events, flood peaks could be slowed through the leaky wood dams reach by over 15 minutes. Data collected during this study suggested that peaks of some events could have been slowed by up to 2 hours and 15 minutes (see Table 3-1), however, it is important to note the limitations of the data collected. For other events peaks were recorded at the same time throughout the reach. This suggests that the slowing of flood peaks occurs at different rates for different event groups. Further research is needed to establish how the maximum slowing of peaks can be achieved.

Based solely upon the statistical analysis of the results alone the only notable variable showing a statistical difference for any Group A event was 'difference between start of rainfall and start of event'. The statistical difference was identified as being between Group A and C events. Group A events were more likely to occur when there

was a short period of time between the start of rainfall and the start of event. This could suggest that NFM leaky wood dams are more likely to work effectively if there is a quick runoff of rainfall into tributaries. Previous research has shown that NFM features intercept this runoff and store it, which reduces such runoff entering main tributaries (Barnsley et al., 2021). Group C events (The bottom of the tributary peaked before the top) had the longest time between the start of rainfall and the start of the event which could suggest that slow runoff into tributaries could negatively impact the effectiveness of the features.

Research by Bokhove et al (2018) suggested that antecedent conditions do play a role in the effectiveness of leaky wood dams. They found that preceding weather conditions affect NFM's effectiveness. Visual analysis of the boxplots of this research suggested a possible difference in mean rainfall values recorded in Group A events compared with the other two groups but as stated above, following statistical analysis the difference was found to be not significant. However, visual analysis of trail camera footage provided further insights into the data collected. Whilst no statistical significance was found for antecedent conditions, when comparing the river before and after each event group it was revealed that the leaky wood dam worked effectively when there were low levels of water behind it before the rainfall event occurred. This suggests that the success of leaky wood dams could be affected by the antecedent hydrological conditions of the tributaries, with them being most successful where tributaries have low flows preceding an event. This therefore does indicate that antecedent conditions do play a role but that further research using a larger number of events is needed to clarify this relationship.

Pattinson and Lane (2012) outlined the complexity of collecting NFM data. Within this research, despite the 18-month record capturing three relatively large events (>1.5 year return period), outliers were present within most of the event group types, indicating that longer periods of data collection are required. By having a longer period of data collection, more events could be captured and analysed which would reduce the impact of outliers on statistical tests. In-field research undertaken by Z. van Leeuwen (Personal Communication, 2021) also experienced data inaccuracies with data outliers present. This research has further exemplified that data collection of the effect of leaky wood dams is difficult and requires a significant amount of data and analysis to determine the impacts. Due to the difficulty in determining if NFM has been

successful, some could question if the significant funding that is currently allocated to NFM projects, such as those funded by Defra (2016) and NERC (2021), offers value for money based purely upon the current scientific knowledge of NFM's effectiveness. The current evidence basis collected by the Environment Agency in the 'Working with Natural Processes - Evidence Directory' (Environment Agency, 2021) provides some evidence of the effectiveness of leaky barriers in certain scenarios, however it concludes that more observed evidence is needed.

## 4.2 Community NFM monitoring

As part of the DEFRA NFM funding for NFM community projects, ongoing monitoring and data collection are specified as being required. This data collection is expected to evaluate if the projects have reduced flood risk to homes, improved habitats and increased biodiversity, supported and developed partnership working with and between communities and contributed to research and development (Defra, 2019). Assessment of community projects and their resources and knowledge and whether they can be undertaken to a high enough standard to withstand scientific rigor is of therefore of great interest.

The site set up and data collection methods used for this research were managed by a paid contractor. Several sites were undergoing monitoring with data collected manually from loggers and trail cameras. Some of the data collected and analysed within this research was compromised due to failures of weirs, as outlined in section 2.3.1. Additionally, the interval of data collection was originally set to 2-minutes but was later reduced to 15-minutes. This was to allow a greater period of time between downloading of data so that it would be less intensive to access and download data. In order to understand if this change had been detrimental or not fieldwork was undertaken to determine the most effective interval level for data collection on these tributaries. During low flow events, the average time taken for water to travel through the reach was 12 minutes and 10 seconds.

A control site directly adjacent to the NFM stream was selected to be used as a direct comparison and allow for greater analysis of the impact of leaky wood dams on the peak flows recorded. Upon review of the data collected from this stream it was clear

that this analysis was not applicable as the control stream varied significantly in catchment size to the NFM stream. This highlights the importance of selected an appropriate control site for future NFM monitoring.

A review of the hydrographs created for the different event types showed that there was limited distinctive peak depths recorded at 15 minute intervals. As flow is likely to increase at peak discharge, it is possible that the hydrographs were unable to capture the distinctive peaks within the 15 minute time interval. This suggests that the 15-minute interval currently used to collect data from these tributaries is inadequate to capture the effects of NFM features. Therefore, reducing the logging time to around 5 minutes would provide a clearer picture of how leaky wood dams perform during flood events, however, it is acknowledged that this would be more time consuming. If ongoing monitoring is required as part of funding NFM projects, consideration should be taken as to how this can be achieved successfully by volunteers who have limited time and resources

This research determined that, for eight events, flood peaks were recorded at the bottom and top of the reach at the same time, suggesting NFM interventions had no effect. Upon reviewing the interval level of data collection, it may not be that these events had no effect rather that the interval level of 15 minutes was insufficient to capture the effect. For this reason, some of the eight events that were no effect events may or may not have slowed flood peaks but not by more than 15 minutes. This could mean that the NFM interventions could have been more successful than reported but without further data collection and monitoring of interventions with an appropriate interval level the outcome of these events is unknown. Wingfield at al., (2019) stated that gathering robust evidence for statistical testing on catchment scales for NFM projects could take decades and may be unachievable. This is due to the difficulty in translating such findings to catchment scales and also the number of variables which can affect each individual flood event.

Currently, there is very little guidance on the monitoring and collecting of data from NFM interventions for community NFM projects. Defra (2019) produced guidance to help some community projects funded by them to collect data. This guidance covers some monitoring and data collection but is generalised and not specific for each community project and does not provide a detailed process for data collection and

monitoring (Defra, 2019). Community projects not funded by the Defra scheme have no guidance on monitoring NFM interventions. For this reason, several networks, including Yorkshires Integrated Catchment Solutions Programme (iCASP) have been providing guidance to NFM practitioners. Without detailed and intervention specific guidance or training, collecting data from NFM sites could be challenging for communities. Research by Sullivan and Molles (2016), found that within community based ecological monitoring programmes training provided by professionals was required to allow volunteers to effectively collect data. For future NFM community projects, specific training could be offered to community NFM projects on how to correctly monitor and collected NFM interventions.

Questionnaire respondents felt that NFM monitoring should be undertaken by government agencies. This may be because the time and expertise required to collect, process and monitor data can be substantial, and this is often mainly reliant upon volunteers. It is possible that community groups would be better placed to complete other important roles when implementing NFM. For instance, community groups can play a significant role in flood data collection, specifically through citizen science, specifically collecting personal qualitative accounts of flood events. Research undertaken by Starkey et al., (2017) demonstrated the value which local community observation data can provide to increase the accuracy of catchment modelling. By combining traditional observations (such as level gauges) with community-based observations, a more accurate catchment response was gathered which was especially useful during flash flood events in which traditional gauges were more likely to poorly represent data collected.

Whilst the results of this study were unable to clearly ascertain when NFM leaky dams were most likely to be effective, results did show that flood peak timings were delayed in nine of the events and, when they were not delayed, on most of the other events they caused no negative impact. For this reason, the case for implementing the features is strong as there is a reasonable chance, specifically 47% of events studied in this research, would reduce flood peak timings and where they do not, they do not cause any negative impacts.

## 4.3 Questionnaire to assess community's feelings on success of NFM community projects

Questionnaires were undertaken to gather the community feelings on the success of the local NFM community project. Previous knowledge and experiences of the 51 participants, ten of whom had previously been engaged with NFM volunteering, were ascertained and compared with their feelings about the impacts of NFM. These were categorised into NFM's effectiveness, environmental impacts, personal impacts, community impacts and delivering NFM.

### 4.3.1 Flood management effectiveness

As previously reported, participants overwhelmingly supported NFM as a flood management tool (90.2%). Analysis of the additional voluntary open-ended comment box responses from the questionnaire provided more detailed information about and nuance to the results. For example, it was noted in responses that many participants understood how NFM can reduce flooding, with many mentioning other potential benefits NFM can create (community, personal and environmental), yet half of the respondents had not directly accessed flood prevention schemes. Therefore, those who have not accessed flood prevention schemes still support NFM. This, compounded with the high rates of self-reported knowledge on NFM, strongly suggests that knowledge about NFM is actively being shared within Calderdale and therefore, the possibility of participant bias towards locally shared knowledge should be acknowledged. Support for NFM measures is not purely based with those who are regularly involved with flood schemes locally, therefore, information regarding NFM is reaching members of the Calderdale population in other ways. This could be due to regular promotion of NFM within Calderdale through community newsletters and social media. Conversely, over a quarter of the respondents were not aware of NFM projects in Calderdale, therefore, locally shared knowledge is not reaching all Calderdale residents, indicating that strategies to promote NFM need to be widened. Location of the respondents and if they had been previously flooded had no effect on their opinions

of NFM community projects suggesting that acceptance within the community is not purely based on previous flood experience or risk of flood exposure. This could mean that NFM projects could be successful within other areas in which flood risk does not impact the whole community.

An overwhelming majority (80%) of participants believed NFM measures were effective at reducing flood risk. An open-ended comment by one participant stated that this was ‘common sense’ and that ‘major case studies across the UK support the efficiency of NFM’. Over a quarter of participants stated they had seen NFM work in Calderdale with some giving personal accounts about the ways they felt NFM was impacting flood risk. One respondent suggested that ‘Hebden Water has not reacted as much as it has in previous similar rainfall events. I'm putting this down to the hundreds of leaky wood debris dams and attenuation ponds in Hardcastle Crags’. Several participants fully believed that the effect of NFM was measurable, but this research has not been able to evidence this with the data collected in Calderdale. This supports the findings of Waylen et al (2018) that evidencing the effect of NFM at reducing flooding is difficult.

These results show a disconnect between current scientific knowledge and community opinions on NFM effectiveness. The belief of the effectiveness within the community is high despite the current absence of scientific findings. This may be due to psychological biases such as confirmation biases in which a person will interpret and favour information which supports their prior beliefs which is reinforced by their interactions and this can occur within water management practises (Pahl-Wostl et al., 2010). Research into communities' previous experiences of flooding through citizen science has noted the importance of personal accounts during flood events to validate and improve traditional methods of data collection (Starkey et al., 2017). Whilst this research currently cannot prove the effect of NFM in reducing flood risk, the community itself believes that they have seen it work. Further community input may help validate and grow the evidence currently being collected.

Some participants highlighted that it was too early to see if NFM works and that there is not enough implementation of NFM in Calderdale to date even through NFM implementation has been ongoing since the formation of STF in 2015 and some aspects of NFM, such as tree planting, have been established long before 2015 by

other charities. This suggests that participants felt that NFM measures in Calderdale required time to mature to work more successfully and much more time is required to find a benefit. One respondent stated that 'I think it WILL, but whether it has yet on any major scale is too early to say'. Research has previously stated that the effect of NFM can take decades to fully establish (Waylen et al., 2018), such as tree planting, and requires widespread implementation (Dadson et al., 2017). These findings suggest the community are aware of this and, whilst they currently do not see an effect of NFM, they do expect an effect in the future, but appear to be willing to wait for this. Whereas a priority of government policy is finding evidence of NFM's effectiveness, which indicates that they require evidence as soon as possible (Defra et al.,2017) to allow them to continue to fund and support NFM in the future and provide evidence that existing measures are providing benefit. At this point the patience of communities and the longevity of their acceptance of NFM is unknown and without further research could impact community NFM projects in the future. With that being said, this research has established a considerable number of novel secondary impacts of community NFM projects, which in themselves could maintain community support for NFM projects.

Other participants stated the lack of evidence and knowledge of NFM's effectiveness as a hurdle to accepting NFM, with one participant stating there was 'no independent evaluation' of NFM and another suggesting they had not seen any evidence of it having an impact. This has been noted as a key barrier to uptake by previous research (Wells et al., 2020) and is a key reason why further research is required.

Participants who had rated their knowledge of flood management in their area as above average were more likely to agree NFM had been effective at reducing flood risk, but those who rated themselves as very knowledgeable were more likely to be sceptical. This could be because those who rate themselves as very knowledgeable understood that the efficacy of NFM is still debated within the scientific community (Wingfield et al., 2019). Whereas those who rated themselves as above average may not be as aware of the lack of evidence. This may indicate that these respondents over-rated their self-reported knowledge and that this may not truly reflect their actual flood knowledge. However, it appears that the respondents already have a realistic expectation of the efficacy of NFM, with the vast majority (88%) of them believing that it should be used in combination with several other methods. One participant noted

that NFM would be unsuitable to address the most serious events and it would require ‘a multi-faceted approach to be fully effective’. Some participants argued that NFM should be used exclusively to reduce flood risk with one response suggesting they were ‘sceptical of the effect of other measures. Man-made flood prevention (eg in Todmorden or Mytholmroyd) seems to me to increase the risk of flooding downstream (eg in Elland and Brighouse)’.

Previous research has suggested the role of NFM in reducing flooding during low frequency events would be limited and NFM alone would be unable to deal with the largest flood events (Dadson et al., 2017). These beliefs are mostly shared by the community, and they are aware of the limitations of NFM. This research found that participants who had accessed a form of flood action or prevention were more likely to completely agree that NFM should be used with several other flood reduction measures which could suggest that when people access flood action or prevention groups they are learning about the role of NFM within the greater flood action plan for an area and when it will be most effective. Additionally, those who had previously accessed a form of flood prevention or action in Calderdale or those who rated themselves as having above average flood knowledge were more likely to be supportive of NFM. These individuals are likely to be regularly engaging with flood management. This could suggest that NFM community projects are more likely to be successful within communities who are regularly engaging in flood management locally.

## 4.3.2 Secondary impacts of NFM

This research looked to establish the community’s feelings on the secondary impacts NFM can provide. These were grouped as environmental impacts, personal impacts and community impacts. Whilst research had previous established that NFM can provide secondary benefits (Wingfield et al., 2019, Lo et al., 2021) there was little research establishing the effects of these on a community.

#### 4.3.2.1 Environmental impacts

This study found that the vast majority of the participants felt that NFM provided environmental benefits to their local area and in open comments stated they had personally seen benefits to their local environment. One response stated that ‘There are more trees, properly managed, less soil erosion, encouragement of natural wildflowers, inviting insects, birds, small mammals etc’. This supports the research by Iacob et al., (2014) who listed the potential ecosystem services which NFM can provide. Over half of the participants were able to list other benefits of NFM besides flood reduction, including biodiversity, tree planting (which is in itself is not a benefit but can provide benefits), habitat creation and wildlife. Most of the benefits listed by the participants are those identified by Iacob et al., (2014) that could occur during an NFM project, and they classed these as provisioning, regulating and supporting ecosystem services. Therefore, this research strengthens their findings about the perceived secondary benefits of NFM measures. It is also expected that these benefits would be present in non-community based NFM projects as these benefits are directly linked with NFM measures.

As previous research had already established the impacts of NFM (Garvey and Paavola, 2021), the participants were asked to rank these benefits in order of importance to them. Respondents ranked habitat creation and increased biodiversity as the most important benefits (after flood risk reduction) and the least important included greater connection to nature and carbon sequestration. Participants stated they did not like the style of question presented as they felt many of these impacts were equally important and could not accurately rank them. This suggests that all secondary impacts were deemed important to them. Future NFM community projects should look to highlight the possible secondary impacts to the community to increase support for NFM.

#### 4.3.2.2 Personal impacts

Participants were asked to establish the personal impact of NFM through a range of questions. A third of respondents felt they had personally benefited from the implementation of NFM, whilst only 20% had previously volunteered with NFM partners, suggesting some participants feel benefit without personally being involved

with NFM. Furthermore, this a significant finding as many more participants than this supported NFM (90.2%), even when they felt no personal benefit from it. Participants who rated their local flood management knowledge as above average were likely to believe they had personally benefited from NFM. In open answers nearly half of respondents were able to explain benefits they had personally experienced with one participant noting the ‘slight reduction in flood risk for my house’.

Some participants within the study felt that NFM installations had impacted their mental health. In open answers many participants listed ways in which they felt their mental health had benefited with one participant stating ‘I believe nature shows us and when we can implement what it has shown us, we feel a greater humble connection to the whole, the holistic way! I have enjoyed and enjoy investigating further. It is stimulating and fulfilling to work with nature's power.’ Previous research has stated the negative impact flooding can have on mental health (Ahern et al., 2005; Carroll et al., 2009; Stanke et al., 2012; Alderman et al., 2012; Fernandez et al., 2015). Improving the mental health of local communities is vital and NFM may be a conduit to providing some mental health benefits.

Whilst people were less convinced that they had personally benefited from NFM’s introduction, those who volunteered stated significant benefits. This is a novel finding. Volunteering has been established as beneficial for individuals who are involved with flood risk management (O’Brien et al., 2014) but this impact has not been established for NFM volunteering before. NFM community projects can rely heavily on volunteer support to run, so understanding what impact these projects have on volunteers is vital. Previous research had established that volunteers could benefit from ecological restoration volunteering (Miles et al. 1998). This research has established that this is also true for NFM volunteering. Mental health benefits were also found for NFM volunteers. This strengthens established research which suggests that volunteering can impact mental health (Sonntag-Öström et al., 2015). Men were statically more likely to volunteer as part of the NFM community project ($p=0.030$). It is well established that male mental health problems are a ‘silent epidemic’ (Baker 2020) and within the UK, suicide is the leading cause of death for men aged between 20 to 49 (Peate, 2015). Men are also less likely to seek support for mental health problems which can exacerbate mental health problems further (Oliver et al., 2005). This could mean that community NFM projects are well placed to provide support for men

suffering with mental health problems and encouraging men to volunteer at NFM projects could provide significant benefits.

This research found that volunteers were connected to their local environment which allowed them to appreciate their environment more. Bratman et al., (2012) found that experiences with nature can bring significant benefits including improved mood and memory. When volunteers feel more connected to their local environment, they could be experiencing some of these benefits. Most volunteers also visited NFM interventions in their own time, meaning that they could also be obtaining these benefits outside of when they are actively volunteering. The overall cumulative effect of this could be significant. It is also pertinent to note that the 32% of respondents stated that they wished to be more involved with the implementation of NFM, specifically nine participants who had never previously volunteered. This is an important untapped resource and finding ways of converting this desire into action is an area which needs research. These findings are extremely important for the longevity of NFM community projects as many community projects are only possible because of the volunteering of the local community. With the growing concern for the mental health of flooded communities (Ahern et al., 2005; Carroll et al., 2009; Stanke et al., 2012; Alderman et al., 2012; Fernandez et al., 2015), NFM community projects could provide a key role in enabling volunteers to access personal benefits. These benefits are unlikely to transfer to non-community NFM projects which are managed by government bodies as these projects would not include active volunteering.

#### 4.3.2.3 Community impacts

Whilst the community felt they had not personally benefited from NFM, it was shown that they felt the community had benefited with residents stating they were able to ‘get back some control’ which ‘empowered people to act positively to manage flood risk in their own homes and wider town’ and that NFM ‘provided people with the opportunity to do something proactive’. This ability to take control of their own flood risk was ‘very empowering’. These are all forms of resilience the community is developing through a community NFM project. This echoes previous research by Nye et al., (2011) who found that community level flood management could provide community

empowerment to manage flood risk. No research has previously linked NFM introduction with community benefits.

Flood resilience is an important factor for flood communities, and with climate change, it is likely that it will become more important in the future (Mehryar and Surminshi, 2021). Flood resilience is especially important within NFM catchments as current knowledge suggests that NFM will not be effective during every flood event, which could mean some flooding is inevitable (Iacob et al., 2014). This study found that participants felt that their community is more resilient to the impact of flooding because of NFM implementation, but these feelings were not echoed with regard to personal flood resilience. This strengthens the findings of Boon (2014) who found that community spirit is a resilience measure and is important in coping with and recovering from flooding. This increase in community resilience is unlikely to occur with traditional top-down approaches to implementing NFM. This exemplifies the need for community based NFM projects in order to develop community resilience to flooding.

Whilst they have felt very little personal benefit, support for NFM and the impact that it could have for the wider community was still strong. This could echo previous research by Howgate and Kenyon (2009), who found that a community felt obligated to implement NFM locally to help reduce flooding for downstream communities. Therefore, NFM implementation could be seen by many in the community as something that is important for the greater good of the community, rather than expecting any personal benefit from it. This could positively affect overall support for NFM in the future. This support for the wider community finding also links to the findings of Forrest et al. (2017), who stated that community flood groups can provide emotional support for communities. As flooded communities are more regularly affected by mental health issues (Ahern et al., 2005; Carroll et al., 2009; Stanke et al., 2012; Alderman et al., 2012; Fernandez et al., 2015) being actively involved in NFM measures may be a way of developing community support which could have a positive impact upon the mental health of the participants.

The participants felt that NFM positively impacted the community. One response stated that ‘practical skills or help manage the impact of flooding has helped us become more resilient as a local community’. This suggests that community NFM projects provide skills not just specifically about NFM, but also provide support for the

impact of flooding more generally. This research has shown that community NFM projects can increase community resilience to the impacts of flooding. With community flood resilience becoming increasingly important within the UK, community NFM projects may be in a unique position to deliver community resilience. Whilst it is still not understood why community NFM projects create greater community flood resilience. This further exemplifies the important wider benefits NFM community projects provide to a community. It should be noted that this research has looked at one community project and the impacts found within Calderdale may not be replicated in other catchments, as community NFM projects are likely to be structured and operated in individual ways meaning they may have different outcomes. However, NFM community projects across the UK should provide a very similar structure to that seen within Calderdale as community NFM projects all require the use of volunteers as well as community engagement. Therefore, this research could be representative of other NFM community projects but further research is required.

These findings overall do not fully explain why participants felt NFM had more impact upon their community recovering from flooding than upon themselves personally and this requires further study.

It has been shown that NFM community projects have a significant impact on local communities who regularly experience flooding, providing support for people individually and for the community as a whole. If NFM projects did not include an element of local community involvement, these benefits would likely be lost or would not be as prominent. The secondary successes of community NFM projects come for the bottom-up approach allowing for communities to create proactive and empowering change within their catchments. Therefore, it is vital that community NFM projects are supported and promoted in the future, not only to gain more evidence of their effectiveness as a flood prevention method but also so that the other multiple benefits are not lost.

## 4.4 Future work

This research focused upon a community NFM project located within Calderdale. Future research could look to assess the impact of community NFM projects within other communities which are already ongoing. This would allow for comparisons of findings as well as allow researchers to determine the success and failures of individual NFM measures and projects to aid future NFM community projects.

This research has highlighted several areas that require further research. These have been organised into 2 categories: the effectiveness of NFM and the secondary community impacts of NFM.

### 4.4.1 Effectiveness of NFM

This research highlighted that instream measures could have successfully slowed the flood peaks during nine events, eight events where flood peaks were not impacted and four events in which the bottom peaked before the top. More research is required to fully understand which antecedent conditions and event rainfall types were most likely to impact the effectiveness of leaky wood dams. It is suggested that localised rain gauges are installed to capture specific rainfall patterns which would directly drain into these tributaries.

This research collected eight events in which flood peaks were determined to not be impacted by interventions. Poor maintenance of the monitoring station itself was a barrier for determining the effect of the intervention. If effective maintenance of the monitoring station was achieved, future research would be able to more accurately determine this effect. These findings were also impacted by the data currently being collected at a 15-minute interval level. Future work could look to reduce the interval of data collection to 5 minutes which would help determine if these types of events still occurred or if flood peaks were slowed by less than 15 minutes. This study also focused on the impact of an individual reach with one set of NFM measures, further research could look to address the impact of several NFM reaches on the overall flood risk of Calderdale.

### 4.4.2 Secondary community benefits

This study found significant impacts for individuals and well as the wider community. Future research could further explore the impacts for individuals by undertaking long form interviews which would provide greater context as to the opinions and beliefs collected within this study. Other methods could also include focus groups to allow greater community discussion around community opinions and values towards NFM.

This study suggests the importance of previous flood knowledge as a determining factor for acceptance of NFM with those rating themselves as very knowledgeable more likely to be pessimistic. Future research could look to further understand this relationship. This research found the acceptance of NFM was high within the community but many suggested that they expected NFM to work more effectively in the future to reduce flood peaks. If NFM cannot be as successful as previously anticipated, it is not known if community support will reduce. Future research could address this through a long-term study of NFM reception within a community.

# 5 Conclusion

NFM community projects are presently understudied and their impacts on flood risk and community acceptance yet to be determined. This research explored the impact of a community NFM project within Calderdale by gathering local communities' feelings and evaluating data collected from interventions managed by a community NFM group.

Data collected from a stretch of stream with 10 leaky wood barriers within Calderdale showed that peaks could have been slowed for nine events out of twenty recorded over an 18-month period. Due to the complexities of collecting and monitoring NFM interventions, the factors which affected the leaky wood dams' effectiveness could not be determined but some variables, notably peak rainfall time to peak depth and time taken between start of rainfall and start of event were shown to be important. This further suggests that antecedent conditions and duration of rainfall could play a role in NFM's effectiveness, but more research is required to fully understand these effects. This research found that in general, when interventions did not slow flood peaks, they had no negative impact on flood risk. For this reason, whilst they may not work effectively during every flood event, by having them in place there is still a chance that flood peaks would be slowed. Whilst others have stated NFM should not be seen as a 'no regret' measure (Iacob et al., 2017), in this case some could view these interventions as a kind of 'no regret' measure and when they do slow flood peaks it is a bonus.

Monitoring of NFM interventions is a complex and difficult process that can require a significant amount of knowledge, time and effort, meaning that some community groups may not have the capabilities to fulfil this role. This study showed the site selection for monitoring NFM features is complicated and requires experience to determine if a site will be successful. These complex issues could suggest the need for further investment in developing hydrographic CBA tools to quickly and effectively analyse the site selected by NFM community groups to determine if they will be appropriate. Completing hydrological assessments of areas selected for NFM interventions would not just benefit community NFM project but would be useful for all

NFM projects by determining catchment scales and determining if multiple interventions would be appropriate.

Further support through funding and guidance for community NFM projects to collect and monitor data would allow for more rigorous data to be collected. With the current NFM data collection, it is still unknown how and when NFM interventions are affecting local flood risk. Uncertainty in the effectiveness of NFM could lead to questions around the value of NFM community projects as specifically a flood reduction strategy given that NFM projects have received £15 million in funding nationally (Defra, 2017) and the evidence basis is still growing as to the effectiveness of NFM. When only viewing NFM has a flood reduction strategy, this argument could be justified but, by considering the breadth of impacts NFM brings to a community, pigeon holing NFM as just a flood reduction strategy would not encapsulate the holistic impacts that NFM can have. By only determining if projects have been successful based solely on their ability to prove they have reduced flood risk would curtail the multiple benefits collected during this study. This research suggests that other NFM community projects within the UK could be creating similar secondary benefits which are not yet being quantified.

Questionnaire responses by the community showed an acceptance of NFM as a flood reduction method. Many suggested that whilst they did not currently feel NFM was impacting flood risk, they had faith that in the future, with greater implementation, they did expect an impact. This could mean that if in the future NFM is not able to deliver its proposed flood reduction benefits then acceptance may falter. However, the findings revealed several novel secondary impacts which were linked to community NFM projects. These benefits were categorised as environmental, personal and community. The community were aware of the secondary environmental impacts that NFM could provide with increased biodiversity and habitat creation being ranked as the most important. These novel findings suggest NFM community projects can have significant positive impacts for individuals, specifically volunteers, as they experienced improving mental health and a greater connection to nature. These impacts are directly linked to community NFM projects and are unlikely to occur if NFM implementation did not involve the community. Since quantifying the monetary value of secondary impacts of NFM is very difficult determining if NFM is ‘worth it’ in a monetary sense is complex. However, by viewing NFM community projects as a holistic practise which can provide significant community, personal and environmental impacts outside of flood reduction

the range of effects NFM community projects provide would be better encapsulated. Accepting the limitations of NFM community projects to reduce flood risk whilst understanding the greater impacts community NFM projects play could outweigh these limitations.

NFM community projects increased community resilience to the impact of flooding which is of ever-increasing importance globally and within the UK. Through NFM community projects individuals within the community were given a greater role within their local flood management which allowed the community to gain control over their own flood risk which increased overall flood resilience to the impact of flooding. Community NFM projects could be a way of delivering resilience to a community whilst providing other useful benefits. NFM community projects could be the catalyst for many other catchments to introduce flood resilience to communities. Flood resilience of a local community may be another way to determine the success of NFM community projects.

NFM community projects are creating important secondary wellbeing benefits. These benefits are being experience outside those directly volunteering within NFM project and suggests a greater cultural shift within NFM communities. These benefits should not be overlooked as they provide significant support for communities who are more at risk of mental health illness and provide a community resilience to the increasing impacts of climate change. Future research and policy should look to further expand on this understanding and provide long term monitoring of the secondary wellbeing benefits experienced within NFM community project. Capturing the wide reaching wellbeing impacts is admittedly complex and would require multiple studies of several community NFM projects. Government focus for NFM policy should look to expand on these findings and include community wellbeing monitoring as part of future NFM community projects.

Within NFM research, success of some NFM projects has been focused on data collection and monitoring the impacts NFM can provide at reducing flood risk. This is due to the desire of research and academics to prove NFM's effectiveness as a flood reduction tool. A holistic approach is growing in popularity with research now highlighting these multiple benefits. This has been further supported by the Environment Agencies 'Working With Natural Processes - Evidence Directory

(Environment Agency, 2021). Using reductionist methods of determining success results in many other benefits being missed, especially those that benefit the community. Through viewing NFM community projects from a holistic perspective the full scope of the impacts NFM can provide for an area can be captured.

All of these points suggest that a changing focus for determining the success of NFM community projects is needed, moving away from the single-minded methods of determining success based purely upon flood reduction effects alone to a holistic evaluation of the impacts community NFM projects have throughout a catchment. Determining this success is admittedly complex but would ensure the wide-ranging impacts of NFM are encompassed.

For future NFM community projects, developing these secondary impacts on local communities may prove to be significantly beneficial and could create new sources of funding. Future UK government projects involving NFM should evaluate the multiple roles community projects could provide and if inclusion of a local community in the project could provide significant benefits that would not be experienced without their involvement.

# 6 References


Aerts, J. C. J. H., W. J. W. Botzen, K. Emanuel, N. Lin, H. de Moel, and E. O. Michel-Kerjan (2014), Evaluating flood resilience strategies for coastal megacities, *Science*, **344**(6183), 473–475, doi:10.1126/science.1248222.

Aerts, J.C., Botzen, W., van der Veen, A., Krywkow, J. and Werners, S., 2008. Dealing with uncertainty in flood management through diversification. *Ecology and Society*, **13**(1).

Ahern, M., Kovats, R.S., Wilkinson, P., Few, R. and Matthies, F., 2005. Global health impacts of floods: epidemiologic evidence. *Epidemiologic reviews*, **27**(1), pp.36-46.

Alderman, K., Turner, L.R. and Tong, S., 2012. Floods and human health: a systematic review. *Environment international*, **47,** pp.37-47.

Allua, S. and Thompson, C.B., 2009. Inferential statistics. *Air Medical Journal*, **28**(4), pp.168-171.

Andersson, K. P., & Ostrom, E. (2008). Analyzing decentralized resource regimes from a polycentric perspective. *Policy Sciences*, **41**, pp.71–93. https://doi.org/10.1007/s11077-007-9055-6

Archer, N.A.L., Bonell, M., Coles, N., MacDonald, A.M., Stevenson, R. and Hallett, P., 2012. The relationship of forest and improved grassland to soil water storage and its implication on Natural Flood Management in the Scottish Borders.

Ashley, Richard M., David J. Balmforth, Adrian J. Saul, and J. D. Blanskby. 2005. "Flooding in the future–predicting climate change, risks and responses in urban areas." Water Science and Technology **52**(5) pp.265-273.

Baker, C., 2020. Mental health statistics for England: prevalence, services and funding.

Barber, N.J. and Quinn, P.F., 2012. Mitigating diffuse water pollution from agriculture using soft-engineered runoff attenuation features. *Area*, **44**(4), pp.454-462.

Bark, RH, Martin-Ortega, J and Waylen, KA (2021). Stakeholders' views on Natural Flood Management: Implications for the nature-based solutions paradigm shift? *Environmental Science and Policy*, **115**. pp. 91-98. ISSN 1462-9011

Barlow, J., Moore, F. and Burgess-Gamble, L., 2014. Working with natural processes to reduce flood risk. R*&D Framework: Science Report SC130004/R2.*

Barnsley, I., Spake, R., Sheffield, J., Leyland, J., Sykes, T. and Sear, D., 2021. Exploring the Capability of Natural Flood Management Approaches in Groundwater-Dominated Chalk Streams. *Water*, **13**(16), p.2212.

Bechtol, V. and Laurian, L., 2005. Restoring straightened rivers for sustainable flood mitigation. *Disaster prevention and management: an international journal*.

Berndtsson, R., Becker, P., Persson, A., Aspegren, H., Haghighatafshar, S., Jönsson, K., Larsson, R., Mobini, S., Mottaghi, M., Nilsson, J. and Nordström, J., 2019. *Drivers of changing urban flood risk: A framework for action. Journal of environmental management*, **240**, pp.47-56.

BGS. 2021. *Geology of Britain viewer*. [Online]. [Accessed on: 28 November 2021]. Available at: https://www.bgs.ac.uk/map-viewers/geology-of-britain-viewer/

Biggam, J., 2018. EBOOK: Succeeding with your Master's Dissertation: A Step-by-Step Handbook: Step-by-step Handbook. *McGraw-Hill Education (UK).*

Bird, D.K., 2009. The use of questionnaires for acquiring information on public perception of natural hazards and risk mitigation–a review of current knowledge and practice. *Natural Hazards and Earth System Sciences*, ***9***(4), pp.1307-1325.

Black, A., Peskett, L., MacDonald, A., Young, A., Spray, C., Ball, T., Thomas, H. and Werritty, A., 2021. Natural flood management, lag time and catchment scale: Results from an empirical nested catchment study. *Journal of Flood Risk Management*, p.e12717.

Blalock, H.M., 1979. Social Statistics. Revised. *New York, NY: McGraw-Hill. Box, GEP, & Cox, DR (1964). An analysis of transformations. Journal of the Royal Statistical Society, Series B (Methodology)*, ***26***(2), pp.211-252.

Bokhove, O., Kelmanson, M.A., Kent, T., Piton, G. and Tacnet, J.M., 2019. Communicating (nature-based) flood-mitigation schemes using flood-excess volume. *River Research and Applications*, **35**(9), pp.1402-1414.

Boon, H.J., 2014. Disaster resilience in a flood-impacted rural Australian town. *Natural hazards*, ***71***(1), pp.683-701.

Braccia, A. and Batzer, D.P., 2008. Breakdown and invertebrate colonization of dead wood in wetland, upland, and river habitats. *Canadian Journal of Forest Research*, **38**(10), pp.2697-2704.

Bragg, O.M., 2002. Hydrology of peat-forming wetlands in Scotland. *Science of the Total Environment*, **294**(1-3), pp.111-129.

Bratman, G.N., Hamilton, J.P. and Daily, G.C., 2012. The impacts of nature experience on human cognitive function and mental *health. Annals of the New York Academy of Sciences*, **1249**(1), pp.118-136.

Calderdale Council 2017. *Section 19 Report. Flood events of November and December 2015*. [Online]. [Accessed 21 November 2021]. Available at: https://www.calderdale.gov.uk/nweb/COUNCIL.minutes_pkg.view_doc?p_Type=AR&p_ID=50542

Calderdale Council. 2021. *Calderdale Demographic Information*. [Online]. [Accessed 21 November 2021]. Available at: <https://www.calderdale.gov.uk/v2/residents/health-and-social-care/joint-strategic-needs-assessment/calderdale-demographic-information>

Carroll, B., Morbey, H., Balogh, R. and Araoz, G., 2009. Flooded homes, broken bonds, the meaning of home, psychological processes and their impact on psychological health in a disaster. *Health & Place*, ***15***(2), pp.540-547.

Chang, M.S., Tseng, Y.L. and Chen, J.W., 2007. A scenario planning approach for the flood emergency logistics preparation problem under uncertainty.

*Transportation Research Part E: Logistics and Transportation Review*, **43**(6), pp.737-754.

Cloke, P., Cook, I., Crang, P., Goodwin, M., Painter, J. and Philo, C., 2004. *Practising human geography*. Sage

Corry, O., 2014. From defense to resilience: Environmental security beyond neo-liberalism. *International political sociology*, **8**(3), pp.256-274.

Creswell, J.W., 1994. Research design.

Dadson, S.J., Hall, J.W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I.P., Lane, S.N. and O'Connell, E., 2017. A restatement of the natural science evidence concerning catchment-based 'natural'FM in the UK. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **473**(2199), p.20160706.

Dankers, R., et al. (2014), First look at changes in flood hazard in the Inter-Sectoral Impact Model Intercomparison Project ensemble, Proc.Natl. *Acad. Sci. U. S. A.*, **111**(9), 3257–3261, doi:10.1073/pnas.1302078110.

De Bruijn, K.M., 2004. Resilience and flood risk management. *Water Policy*, ***6***(1), pp.53-66.

De Visscher, M., Nyssen, J., Pontzeele, J., Billi, P. & Frankl, A. (2013). Spatio-temporal sedimentation patterns in beaver ponds along the Chevral river, Ardennes, Belgium. *Hydrological Processes* **28** (4) 1602-1615. https://doi.org/10.1002/hyp.9702

Defra et al. 2017. Schemes across the country to receive £15 million of natural flood management funding [Online]. [Accessed: 21 November 2021]. Available at: https://www.gov.uk/government/news/schemes-across-the-country-to-receive-15-million-of-natural-flood-management-funding [

Defra, 2012. *UK Climate Change Risk Assessment: Government Report*. [Accessed 29 October 2021] Available at: https://www.gov.uk/government/publications/uk-climate-change-risk-assessmentgovernment-report

Defra. 2011. *Flood and coastal resilience partnership funding*. [Accessed 29 October 2021] Available at https://www.gov.uk/government/publications/flood-andcoastal-resilience-partnership-funding

Defra. 2019. *Reporting, monitoring and evaluating the DEFRA funded Natural Flood Management projects*. [Online]. [Accessed: 21 November 2021]. Available at: https://catchmentbasedapproach.org/wp-content/uploads/2019/08/NFM-MonitoringFull_v6.pdf

Di Baldassarre, G., A. Montanari, H. Lins, D. Koutsoyiannis, L. Brandimarte, and G. Bl€oschl (2010), Flood fatalities in Africa: From diagnosis to mitigation, *Geophys. Res. Lett*., **37**, L22402, doi:10.1029/20 10GL045467.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., et al. (2015). Debates-perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research*, **51**, 4770– 4781. https://doi.org/10.1002/2014WR016416

Digimap.edina.ac.uk. 2021. Digimap. [Online]. [Accessed 21 November 2021]. Available at: <https://digimap.edina.ac.uk/>

Disse, M., Johnson, T.G., Leandro, J. and Hartmann, T., 2020. Exploring the relation between flood risk management and flood resilience. *Water Security*, **9**, p.100059.

Dittrich, R., Ball, T., Wreford, A., Moran, D. and Spray, C.J., 2019. A cost-benefit analysis of afforestation as a climate change adaptation measure to reduce flood risk. *Journal of Flood Risk Management*, **12**(4), p.e12482.

Ellis, N., Anderson, K. and Brazier, R., 2021. Mainstreaming natural flood management: A proposed research framework derived from a critical evaluation of current knowledge. *Progress in Physical Geography: Earth and Environment*, p.0309133321997299.

Environment Agency. 2016. Calderdale flood action plan. [Online]. [Accessed 21 November 2021]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/upload

s/attachment_data/file/865606/2019_12_Calderdale_FAP_-_4th_Publication.pdf

Environment Agency. 2021. Working with Natural Processes – Evidence Directory. [Online] [Accessed 7 April 2022]. Available at: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/working-with-natural-processes-to-reduce-flood-risk

Environment Agency. 2022. Flood and coastal erosion risk management report: 1 April 2018 to 31 March 2019. [Online]. [Accessed 17 March 2022]. Available at: https://www.gov.uk/government/publications/flood-and-coastal-risk-management-national-report/flood-and-coastal-erosion-risk-management-annual-report-1-april-2018-to-31-march-2019

Eyeoncalderdale.com. 2021. Past Floods in the Calder Valley. [Online]. [Accessed 21 November 2021].Available at: <https://eyeoncalderdale.com/past-floods-in-the-calder-valley>

Fernandez, A., Black, J., Jones, M., Wilson, L., Salvador-Carulla, L., Astell-Burt, T. and Black, D., 2015. Flooding and mental health: a systematic mapping review. *PloS one*, ***10***(4), p.e0119929.

Flood Hub. 2021. Natural flood management. [Online]. [Accessed 21 November 2021]. Available at: https://thefloodhub.co.uk/nfm/#section-5.

Flowerdew, R. and Martin, D. eds., 2005. *Methods in human geography: a guide for students doing a research project*. Pearson Education.

Forrest, S., Trell, E.M. and Woltjer, J., 2017. Flood Groups in England: Flood Groups in England: Governance arrangements and contribution to flood resilience. Routledge.

Forrest, S., Trell, E.M. and Woltjer, J., 2019. Civil society contributions to local level flood resilience: Before, during and after the 2015 Boxing Day floods in the Upper Calder Valley. *Transactions of the Institute of British Geographers*, ***44***(2), pp.422-436.

Garvey, A. and Paavola, J., 2021. Community action on natural flood management and the governance of a catchment-based approach in the UK. *Environmental Policy and Governance*.

Gibbs, G.R., 2007. Thematic coding and categorizing. *Analyzing qualitative data*, ***703***, pp.38-56.

Girden, E.R., 1992. *ANOVA: Repeated measures* (No. 84). Sage.

Grabowski, R.C., Gurnell, A.M., Burgess-Gamble, L., England, J., Holland, D., Klaar, M.J., Morrissey, I., Uttley, C. and Wharton, G., 2019. The current state of the use of large wood in river restoration and management. *Water and Environment Journal*, **33**(3), pp.366-377.

Gregory, K.J. and Davis, R.J., 1992. Coarse woody debris in stream channels in relation to river channel management in woodland areas. *Regulated Rivers: Research & Management*, **7**(2), pp.117-136.

Haney, T.J. and McDonald-Harker, C., 2017. "The river is not the same anymore": environmental risk and uncertainty in the aftermath of the High River, Alberta, flood. *Social Currents*, ***4***(6), pp.594-612.

Hankin, B., Hewitt, I., Sander, G., Danieli, F., Formetta, G., Kamilova, A., Kretzschmar, A., Kiradjiev, K., Wong, C., Pegler, S. and Lamb, R., 2020. A risk-based network analysis of distributed in-stream leaky barriers for flood risk management. *Natural Hazards and Earth System Sciences*, **20**(10), pp.2567-2584.

Harris, M., Shaw, D., Scully, J., Smith, C.M. and Hieke, G., 2017. The involvement/exclusion paradox of spontaneous volunteering: New lessons and theory from winter flood episodes in England. *Nonprofit and voluntary sector quarterly*, **46**(2), pp.352-371.

Hegney, D., Ross, H., Baker, P., Rogers-Clark, C., King, C., Buikstra, E., Desley, G., Stallard, L., 2008. Identification of Personal and Community Resilience that Enhance Psychological Wellness: A Stanthorpe Study. *University of Southern Queensland, Toowoomba, Queensland*.

Henderson, F., Steiner, A., Farmer, J. and Whittam, G., 2020. Challenges of community engagement in a rural area: The impact of flood protection and policy. *Journal of Rural Studies*, ***73***(June 2019), pp.225-233.

Hinkel, J., D. Lincke, A. T. Vafeidis, M. Perrette, R. J. Nicholls, R. S. J. Tol, B. Marzeion, X. Fettweis, C. Ionescu, and A. Levermann (2014), Coastal flood damage and adaptation costs under 21st century sea-level rise, *Proc. Natl. Acad. Sci. U. S. A*., **111**(9), 3292–3297, doi:10.1073/pnas.1222469111

Howgate, O.R. and Kenyon, W., 2009. Community cooperation with natural flood management: a case study in the Scottish Borders. *Area*, ***41***(3), pp.329-340.

Hughes, R.M., Kaufmann, P.R. and Weber, M.H., 2011. National and regional comparisons between Strahler order and stream size. *Journal of the North American Benthological Society*, ***30***(1), pp.103-121.

Iacob, O., Rowan, J.S., Brown, I. and Ellis, C., 2014. Evaluating wider benefits of natural flood management strategies: an ecosystem-based adaptation perspective. *Hydrology Research*, ***45***(6), pp.774-787.

IPCC 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability report.

Ingirige, M.J.B., Russell, R.C., 2015. Investigating SME resilience to flooding: the Braunton report. Available at: http://www.arcc-network.org.uk/wp-content/pdfs/

JISC. 2021. Who we are and what we do. [Online]. [Accessed: 6 November 2021] Available at: https://www.jisc.ac.uk/about/who-we-are-and-what-we-do. ().

Jongman, B., S. Hochrainer-Stigler, L. Feyen, J. C. J. H. Aerts, R. Mechler, W. J. W. Botzen, L. M. Bouwer, G. Pflug, R. Rojas, and P. J. Ward(2014), Increasing stress on disaster-risk finance due to large floods, *Nat. Clim. Change*, **4**(4), 264–268, doi:10.1038/nclimate2124.

Juárez, A., Alfredsen, K., Stickler, M., Adeva-Bustos, A., Suárez, R., Seguín-García, S. and Hansen, B., 2021. A Conflict between Traditional Flood Measures and Maintaining River Ecosystems? A Case Study Based upon the River Lærdal, Norway. *Water*, **13**(14), p.1884.

Keating, A., Campbell, K., Szoenyi, M., McQuistan, C., Nash, D. and Burer, M., 2017. Development and testing of a community flood resilience measurement tool. *Natural Hazards and Earth System Sciences*, *17*(1), pp.77-101.

Keeton, W.S., Kraft, C.E. and Warren, D.R., 2007. Mature and old-growth riparian forests: structure, dynamics, and effects on Adirondack stream habitats. *Ecological Applications*, **17**(3), pp.852-868.

Kiehl, J. 2011. Lessons from Earth's past. *Science,* **331**, 158–159.

Kim, H. (2017). Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative dentistry & endodontics*, ***42***(2), 152–155.https://doi.org/10.5395/rde.2017.42.2.152

Konare, A., Zakey, A.S., Solmon, F., Giorgi, F., Rauscher, S., Ibrah, S. and Bi, X., 2008. A regional climate modeling study of the effect of desert dust on the West African monsoon. *Journal of Geophysical Research: Atmospheres*, **113**(D12).

Kumar, R. and Bhardwaj, A., 2015. Probability analysis of return period of daily maximum rainfall in annual data set of Ludhiana, Punjab*. Indian Journal of Agricultural Research*, **49**(2), pp.160-164.

Lai, A., Leoni, G. and Stacchezzini, R., 2014. The socializing effects of accounting in flood recovery. *Critical Perspectives on Accounting*, **25**(7), pp.579-603.

Lane, S.N., 2017. Natural Flood Management. Wiley Interdisciplinary Reviews: *Water*, **4**(3), p.e1211.

Lavers, T. and Charlesworth, S., 2018. Opportunity mapping of natural flood management measures: a case study from the headwaters of the Warwickshire-Avon. *Environmental Science and Pollution Research*, ***25***(20), pp.19313-19322.

Liao, K. H. (2014). From flood control to flood adaptation: A case study on the Lower Green River Valley and the City of Kent in King County, Washington. *Natural Hazards*, **71**(1), 723– 750. https://doi.org/10.1007/s11069-013-0923-4

Lindsay, J.B., 2016. The practice of DEM stream burning revisited. *Earth Surface Processes and Landforms*, ***41***(5), pp.658-668.

Liu, M., 2017. Web survey experiments on matrix questions. *Computers in Human Behavior*, *67*, pp.61-72.

Lo, H.W., Smith, M., Klaar, M. and Woulds, C., 2021. Potential secondary effects of in-stream wood structures installed for natural flood management: A conceptual model. *Wiley Interdisciplinary Reviews: Water*, **8**(5), p.e1546.

Lowe, D., Ebi, K.L. and Forsberg, B., 2013. Factors increasing vulnerability to health effects before, during and after floods. *International journal of environmental research and public health*, **10**(12), pp.7015-7067.

Marshall, M.R., Ballard, C.E., Frogbrook, Z.L., Solloway, I., McIntyre, N., Reynolds, B. and Wheater, H.S., 2014. The impact of rural land management changes on soil hydraulic properties and runoff processes: results from experimental plots in upland UK. *Hydrological Processes*, ***28***(4), pp.2617-2629.

Maskrey, S.A., Mount, N.J., Thorne, C.R. and Dryden, I., 2016. Participatory modelling for stakeholder involvement in the development of flood risk management intervention options. *Environmental modelling & software*, ***82***, pp.275-294.

McCuen, R.H., 2005. Hydrologic analysis and design. *Journal of the American Water Resources Association*, ***40***(3), p.838.

McEwen, L., Garde-Hansen, J., Holmes, A., Jones, O. and Krause, F., 2017. Sustainable flood memories, lay knowledges and the development of community resilience to future flood risk. *Transactions of the Institute of British Geographers*, ***42***(1), pp.14-28.

McGuirk, P.M. and O'Neill, P., 2016. Using questionnaires in qualitative human geography.

McLafferty, S.L., 2003. Conducting questionnaire surveys. *Key methods in geography*, ***1***(2), pp.87-100.

Mees, H., Alexander, M., Gralepois, M., Matczak, P. and Mees, H., 2018. Typologies of citizen co-production in flood risk governance. *Environmental Science & Policy*, ***89***, pp.330-339.

Mehring, P., Geoghegan, H., Cloke, H.L. and Clark, J.M., 2018. What is going wrong with community engagement? How flood communities and flood authorities construct engagement and partnership working. Environmental science & policy, **89**, pp.109-115.

Mehryar, S. and Surminski, S., 2021. National laws for enhancing flood resilience in the context of climate change: potential and shortcomings. *Climate Policy*, ***21***(2), pp.133-151.

Merz, B., Hall, J., Disse, M. and Schumann, A., 2010. Fluvial flood risk management in a changing world. Natural Hazards and Earth System Sciences, ***10***(3), pp.509-527.

Met office. 2021. Past weather events. [Online]. [Accessed 25 October 2021]. Available from: https://www.metoffice.gov.uk/weather/learn-about/past-uk-weather-events

Metcalfe, P., Beven, K., Hankin, B. and Lamb, R., 2017. A modelling framework for evaluation of the hydrological impacts of nature-based approaches to flood risk management, with application to in-channel interventions across a 29-km2 scale catchment in the United Kingdom. *Hydrological Processes*, **31**(9), pp.1734-1748.

Miles, I., Sullivan, W.C. and Kuo, F.E., 1998. Ecological restoration volunteers: the benefits of participation. *Urban ecosystems*, **2**(1), pp.27-41.

Montz, B. E., & Tobin, G. A. (2008). Livin' large with levees: Lessons learned and lost. *Natural Hazards Review*, **9**(3), 150– 157. https://doi.org/10.1061/(ASCE)1527-6988(2008)9:3(150)

Moore, R.D., 2005. Slug injection using salt in solution. *Streamline Watershed Management Bulletin*, **8**(2), pp.1-6.

Mori, K. and Perrings, C., 2012. Optimal management of the flood risks of floodplain development. Science of the total environment, **431**, pp.109-121.

Muhawenimana, V., Wilson, C.A., Nefjodova, J. and Cable, J., 2021. Flood attenuation hydraulics of channel-spanning leaky barriers. *Journal of Hydrology*, **596**, p.125731.

Mullins, A. and Soetanto, R., 2011. Enhancing community resilience to flooding through social responsibility. *International Journal of Safety and Security Engineering*, ***1***(2), pp.115-125.

NFM Research Programme. 2021. *Projects*. [Online]. [Accessed 21 November 2021]. Available at: https://research.reading.ac.uk/nerc-nfm/projects/.

Nienhuis, P.H. and Leuven, R.S.E.W., 2001. River restoration and flood protection: controversy or synergism?. *Hydrobiologia*, ***444***(1), pp.85-99.

Ntontis, E., Drury, J., Amlot, R., Rubin, G. J., & Williams, R. (2018). Community resilience and flooding in UK guidance: a critical review of concepts, definitions, and their implications. *Journal of Contingencies and Crisis Management*. https://doi.org/10.1111/1468-5973.12223

Nye, M., Tapsell, S. and Twigger-Ross, C., 2011. New social directions in UK flood risk management: moving towards flood risk citizenship*?. Journal of flood risk management*, **4**(4), pp.288-297.

O'Brien, L., Ambrose-Oji, B., Morris, J. and Edwards, D., 2014, September. Civil society and flood resilience: Characterising flood risk volunteers and understanding motivations and benefits*. In 20th Voluntary Sector and Volunteering Research Conference.*

Odén, A. and Wedel, H., 1975. Arguments for Fisher's permutation test. *The Annals of Statistics*, pp.518-520.

Oliver, M.I., Pearson, N., Coe, N. and Gunnell, D., 2005. Help-seeking behaviour in men and women with common mental health problems: cross-sectional study. *The British Journal of Psychiatry*, **186**(4), pp.297-301.

Ostertagova, E., Ostertag, O. and Kováč, J., 2014. Methodology and application of the Kruskal-Wallis test. In *Applied Mechanics and Materials.* **611**. pp. 115-120). Trans Tech Publications Ltd.

Ouyang, S., Zhou, J., Li, C., Liao, X. and Wang, H., 2015. Optimal design for flood limit water level of cascade reservoirs. *Water resources management*, **29**(2), pp.445-457.

Ozer, D.J., 1985. Correlation and the coefficient of determination. *Psychological bulletin*, ***97***(2), p.307.

Paavola, J. (2009). From market failure paradigm to an institutional theory of environmental governance. *Economia delle fonti di energia e dell' ambiente*., **1**, 87–101

Pahl-Wostl, C., Jeffrey, P., Isendahl, N. and Brugnach, M., 2011. Maturing the new water management paradigm: progressing from aspiration to practice. *Water resources management*, **25**(3), pp.837-856.

Pattison, I. and Lane, S. N.: The link between land-use management and fluvial flood risk, *Prog. Phys. Geography*., **36**(1), 72–92, doi:10.1177/0309133311425398, 2012.

Pattison, I. and Lane, S.N., 2012. The link between land-use management and fluvial flood risk: A chaotic conception?. *Progress in Physical Geography*, **36**(1), pp.72-92.

Peate, I., 2015. Stemming the silent epidemic of male suicide. *Independent Nurse*, 2015 (**13**), pp.29-34.

Penning-Rowsell, E., & Johnson, C. (2015). The ebb and flow of power: British flood risk management and the politics of scale. *Geoforum*, **62**, pp.131–142. https://doi.org/10.1016/j.geoforum.2015.03.019

Philip, L.J., 1998. Combining quantitative and qualitative approaches to social research in human geography—an impossible mixture?. *Environment and planning A*, ***30***(2), pp.261-276.

Pilkington, M., Walker, J., Maskill, R., Allott, T. and Evans, M., 2015. Restoration of Blanket bogs; flood risk reduction and other ecosystem benefits. *Final report*

*of the Making Space for Water project: Moors for the Future Partnership, Edale.*

Posthumus, H., Hewett, C.J.M., Morris, J. and Quinn, P.F., 2008. Agricultural land use and flood risk management: engaging with stakeholders in North Yorkshire. *Agricultural Water Management*, **95**(7), pp.787-798.

Ran, J. and Nedovic-Budic, Z., 2016. Integrating spatial planning and flood risk management: A new conceptual framework for the spatially integrated policy infrastructure. *Computers, Environment and Urban Systems*, **57**, pp.68-79.

Rotolo, T. and Berg, J.A., 2011. In times of need: An examination of emergency preparedness and disaster relief service volunteers. *Nonprofit and Voluntary Sector Quarterly*, ***40***(4), pp.740-750.

Rubinato, M., Nichols, A., Peng, Y., Zhang, J.M., Lashford, C., Cai, Y.P., Lin, P.Z. and Tait, S., 2019. Urban and river flooding: Comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs. *Water science and engineering*, ***12***(4), pp.274-283.

Salazar, L., 1994. Irrigation Training Manual. Planning, Design, Operation, and Management of Small-Scale Irrigation Systems [and] Irrigation Reference Manual. A Technical Reference to Be Used with the Peace Corps Irrigation Training Manual T0076 in the Selection, Planning, Design, Operation, and Management of Small-Scale Irrigation Systems.

Sepa. 2016. *Natural FM Handbook*. Stirling: SEPA

Short, C., Clarke, L., Carnelli, F., Uttley, C. and Smith, B., 2018. Capturing the multiple benefits associated with nature-based solutions: Lessons from a natural FM project in the Cotswolds, UK. *Land degradation & development*, **30**(3), pp.241-252.

Shuttleworth, E.L., Evans, M.G., Pilkington, M., Spencer, T., Walker, J., Milledge, D. and Allott, T.E., 2019. Restoration of blanket peat moorland delays stormflow from hillslopes and reduces peak discharge. Journal of Hydrolog, **2**, p.100006.

Sims, R., Medd, W., Mort, M. and Twigger-Ross, C., 2009. When a “home” becomes a “house”: care and caring in the flood recovery process. *Space and culture*, **12**(3), pp.303-316.

Skerratt, S., Steiner, A., 2013. Working with communities-of-place: complexities of empowerment. *Local Econ*. **28** (3), 320–338.

Slow The Flow. About us. 2021. [Online] [Accessed 30 October 2021]. Available at: https://slowtheflow.net.

Sonntag-Öström, E., Stenlund, T., Nordin, M., Lundell, Y., Ahlgren, C., Fjellman-Wiklund, A., Järvholm, L.S. and Dolling, A., 2015. “Nature's effect on my mind”–Patients’ qualitative experiences of a forest-based rehabilitation programme. *Urban Forestry & Urban Greening*, **14**(3), pp.607-614.

Spray, C., Ball, T. and Rouillard, J., 2009. Bridging the water law, policy, science interface: flood risk management in Scotland. *Journal of Water law*, **20**(2-3), pp.165-174.

Stanke, C., Murray, V., Amlôt, R., Nurse, J. and Williams, R., 2012. The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. *PLoS currents*, ***4***.

Stroud District Council. (2017) Completed projects and case studies. [Online]. [Accessed 30 November 2021]. Available at www.stroud.gov.uk/environment/flooding-and-drainage/stroud-rural-sustainable-drainage-rsudsproject/completed-projects-and-case-studies

Sullivan, J.J. and Molles, L.E., 2016. Biodiversity monitoring by community-based restoration groups in New Zealand. *Ecological Management & Restoration*, **17**(3), pp.210-217.

Sung, K., Jeong, H., Sangwan, N. and Yu, D.J., 2018. Effects of flood control strategies on flood resilience under sociohydrological disturbances. *Water Resources Research*, ***54***(4), pp.2661-2680.

Taylor, M., Wells, G., Howell, G. and Raphael, B., 2012. The role of social media as psychological first aid as a support to community resilience building. *Australian Journal of Emergency Management*, **27**(1), pp.20-26.

Tempest, E.L., English National Study on Flooding and Health Study Group, Carter, B., Beck, C.R. and Rubin, G.J., 2017. Secondary stressors are associated with probable psychological morbidity after flooding: a cross-sectional analysis. *The European Journal of Public Health*, **27**(6), pp.1042-1047.

Thomas, H. and Nisbet, T., 2012. Modelling the hydraulic impact of reintroducing large woody debris into watercourses. *Journal of Flood Risk Management*, **5**(2), pp.164-174.

Twigger-Ross, C., Orr, P., Brooks, K. and Saduaskis, R., 2016. Citizen involvement in flood risk governance: Flood groups and networks. *In E3S Web of Conferences* (Vol. 7, p. 17006). EDP Sciences.

UK GOV. 2021. National Resilience Strategy: Call for Evidence. [Online]. [Accessed 21 November 2021]. Available at: <https://www.gov.uk/government/consultations/national-resilience-strategy-call-for-evidence>

Walker-Springett, K., Butler, C. and Adger, W.N., 2017. Wellbeing in the aftermath of floods. *Health & place*, ***43***, pp.66-74.

Waylen, K.A., Holstead, K.L., Colley, K. and Hopkins, J., 2018. Challenges to enabling and implementing Natural Flood Management in Scotland. *Journal of Flood Risk Management*, **11**, pp.S1078-S1089.

Wedawatta, G., Ingirige, B., Proverbs, D., 2014. Small businesses and flood impacts: the case of the 2009 flood event in Cockermouth. *J. Flood Risk Manag.* **7** (1), 42–53.

Wells, J., Labadz, J.C., Smith, A. and Islam, M.M., 2020. Barriers to the uptake and implementation of natural flood management: A social-ecological analysis. *Journal of flood risk management*, **13**, p.e12561.

Wesselink, A., Warner, J., Syed, M.A., Chan, F., Tran, D.D., Huq, H., Huthoff, F., Le Thuy, F., Le Thuy, N., Pinter, N. and Van Staveren, M., 2015. Trends in flood risk management in deltas around the world: Are we going 'soft'. *International Journal of Water Governance*, **3**(4), pp.25-46.

Whittle, R., Walker, M., Medd, W. and Mort, M., 2012. Flood of emotions: emotional work and long-term disaster recovery. *Emotion, Space and Society*, **5**(1), pp.60-69.

WHO, 2017. Strengthening resilience: a priority shared by Health 2020 and the Sustainable Development Goals. [Online]. [Accessed 21 November 2021]. WHO Regional Office for Europe. Available at: <https://www.euro.who.int/__data/assets/pdf_file/0005/351284/resilience-report-20171004-h1635.pdf>

Wilkinson, M., Quinn, P., Ghimire, S., Nicholson, A. and Addy, S., 2014, May. The use of Natural Flood Management to mitigate local flooding in the rural landscape. In *EGU General Assembly Conference Abstracts* (p. 9878).

Wilson, L., Wilson, J., Holden, J., Johnstone, I., Armstrong, A. and Morris, M., 2011. The impact of drain blocking on an upland blanket bog during storm and drought events, and the importance of sampling-scale. *Journal of Hydrology*, ***404***(3-4), pp.198-208.

Wingfield, T., Macdonald, N., Peters, K., Spees, J. and Potter, K., 2019. Natural flood management: Beyond the evidence debate. *Area*, **51**(4), pp.743-751.

Wingfield, T.A., Macdonald, N., Peters, K. and Spees, J., 2021. Barriers to mainstream adoption of catchment wide Natural Flood Management, a transdisciplinary problem framing study of delivery practice. *Hydrology and Earth System Sciences Discussions*, pp.1-34.

Woolson, R.F., 2007. Wilcoxon signed-rank test. *Wiley encyclopedia of clinical trials*, pp.1-3.

Young, W.J., 1991. Flume study of the hydraulic effects of large woody debris in lowland rivers. *Regulated rivers: research & management*, **6**(3), pp.203-211.

Zibran, M.F., 2007. Chi-squared test of independence. *Department of Computer Science, University of Calgary, Alberta, Canada*, pp.1-7.

# 7 Appendix

# Appendix A

Questionnaire Template

# Natural Flood Management in Calderdale questionnaire

## Page 1: Introduction

**Title of the research project thesis**: Examination of the impacts of Natural Flood Management (NFM) within a catchment: An analysis of flood reduction capabilities and community reception.

This questionnaire will take between 10 to 30 minutes to complete depending on how you choose to answer the questions.

By completing this questionnaire you are giving your consent to take part in this research.

Thank you for taking part in this research.

**If you wish to learn more about this research and/or would like to access the participant information sheet.**

**We suggest that everyone reads the information sheet before completing the questionnare. To access the information document, please visit the participant information sheet**

**Contact for further information**

| Role | Name | Contact details |
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| Researcher | Sophie Tankard | Email: gysjt@leeds.ac.uk |
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## Page 2: Natural flood management

1. How would you rate your current understanding of the impact of flooding?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Very knowledgable | Above average | Average | Below average | Very little knowledge |
|---|---|---|---|---|---|
| How would you rate your current understanding of the impact of flooding? | ☐ | ☐ | ☐ | ☐ | ☐ |

1.a. Can you explain your answer further? *Optional*

2. How would you rate your current understanding of flood management?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Very knowledgable | Above average | Average | Below average | Very little knowledge |
|---|---|---|---|---|---|
| How would you rate your current understanding of the management of the impact of flooding? | ☐ | ☐ | ☐ | ☐ | ☐ |

2.a. Can you explain your answer further? *Optional*

3. How knowledgeable do you feel you are about flood management in your area?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Very knowledgable | Above average | Average | Below average | Very little knowledge |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| How knowledgeable do you feel you are about flood management in your area? | ☐ | ☐ | ☐ | ☐ | ☐ |

3.a. Can you give examples of any flood management you are aware of in the area? *Optional*

4. Have you been personally affected by flooding within your area?

- ○ Yes
- ○ No
- ○ Not sure

4.a. From the list below, how have you personally been affected by flooding?

- ○ My house/property has been flooded
- ○ My business has been flooded
- ○ I have been unable to access local services because they have been flooded
- ○ I have been unable to access local services because access to them was restricted due to flooding
- ○ I was unable to travel within the valley because of flooding
- ○ Other

4.a.i. If you selected Other, please provide details:

5. Have you ever accessed any form of flood action or prevention within Calderdale? (for example, you may have joined a online flood group)

- ☐ Yes
- ☐ No
- ☐ Not Sure

5.a. Have you ever accessed any form of flood action or prevention within Calderdale? You can select as many answers that apply to you.

Please select no more than 12 answer(s).

- [ ] I have attended flood meetings
- [ ] I have attended flood scheme consultations
- [ ] I have attended a workshop to develop a flood action plan
- [ ] I have helped volunteer to clean up after a flood event
- [ ] I am/have been a flood warden
- [ ] I have received a grant for property level flood resilience
- [ ] I have been involved with or raised money for Watermark
- [ ] I have volunteered with a flood charity
- [ ] I have joined online flood groups
- [ ] I have done my own research
- [ ] I accessed online website such as Eye on Calderdale
- [ ] Other

*5.a.i.* If you selected Other, please specify:

*5.a.ii.* What do you feel you have learnt and/or gained from this experience? *Optional*

*6.* Have you heard of the term 'Natural Flood Management (NFM)' before?'

- ○ Yes
- ○ No
- ○ Not Sure

*6.a.* How knowledgeable you are with regards to natural flood management?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Very knowledgable | Above average | Average | Below average | Very little knowledge |
|---|---|---|---|---|---|
| How knowledgeable you are with regards to natural flood management? | ☐ | ☐ | ☐ | ☐ | ☐ |

6.a.i. Where did you learn/ hear about natural flood management? *Optional*

7. Natural Flood Management (NFM) is a flood management tool used to reduce the risk of flooding using natural processes. An example of this would be installing woody dams, tree planting or creating wetlands to store flood water. These processes aim to reduce and slow the flow of water entering a river system.

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither disagree nor agree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| After reading this description, do you feel NFM is a flood management tool you support? | ☐ | ☐ | ☐ | ☐ | ☐ |

7.a. Can you explain your opinion of NFM as a flood management tool? *Optional*

8. Have you ever volunteered for organisations and/or charities that are delivering natural flood management?

- ☐ Yes
- ☐ No
- ☐ Not Sure

8.a. What organisation and/or charities have you been involved with in Calderdale? You can select as many answers that apply to you.

Please select no more than 8 answer(s).

- ☐ I have volunteered with Treesponsibility
- ☐ I have volunteered with Slow the Flow
- ☐ I have volunteered with Calder Future
- ☐ I have volunteered with Yorkshire Wildlife Trust
- ☐ I have volunteered with Moors for the Future
- ☐ I have volunteered with Forustrees
- ☐ I have volunteered with the National Trust

- [ ] Other

8.a.i. If you selected Other, please specify:

8.a.ii. What made you decide to volunteer? *Optional*

8.a.iii. What do you feel you have learnt and/or gained from this experience? *Optional*

8.a.iv. Have you noticed any benefits through volunteering? If so, please provide details *Optional*

8.a.v. Do you feel this volunteering opportunity has impacted your mental health? *Optional*

- ○ Yes
- ○ No
- ○ Not sure

8.a.v.a. How do you feel your mental health has been impacted?

8.a.vi. How do you feel about the statement **'I feel more connected to my local environment when I volunteer to implement natural flood management interventions'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

*8.a.vi.a.* Can you explain the above feelings about the statement 'I feel more connected to my local environment when I volunteer to implement natural flood management'? Please explain below. *Optional*

*8.a.vii.* Have you ever visited NFM interventions within Calderdale in your own free time? This does not include when you are actively volunteering. *Optional*

- ○ Yes
- ○ No
- ○ Not Sure

*8.a.vii.a.* What were the reasons why you visited NFM interventions in your own time?

*8.b.* In the future, would you be interested in volunteering for NFM projects? Please explain why.

*9.* How would you rate your awareness of NFM projects that are happening in Calderdale?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Very knowledgable | Above average | Average | Below average | Very little knowledge |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

*9.a.* Can you explain your answer further? *Optional*

## Page 3: Natural flood management in Calderdale

*10.* How do you feel about the statement '**I believe NFM has reduced flood risk in Calderdale'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

*10.a.* Please explain why you feel this way. *Optional*

*11.* How do you feel about the statement **'I wish to be more involved with the implementation of NFM' (e.g. planning, designing and implementing)?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

*11.a.* Why would you wish to be more/less involved with the implementation of NFM? *Optional*

*12.* How do you feel about the statement **'I believe that NFM measures are an effective tool at reducing flood risk'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

*12.a.* Please explain why you feel this way. *Optional*

13. How do you feel about the statement **'I feel NFM should be used with several other measures to reduce flood risk'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

13.a. Please explain why you feel this way.

14. How do you feel about the statement **'I believe NFM is improving my local environment. (e.g. nature, ecosystems and wildlife) '?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree or disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select | ☐ | ☐ | ☐ | ☐ | ☐ |

14.a. Please explain why you feel this way. *Optional*

15. How do you feel about the statement **'I believe I have personally benefited from the implementation of NFM'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ |

15.a. Please explain why you feel this way. *Optional*

16. How do you feel about the statement **'I believe my community has benefited from the implementation of NFM' (e.g. community spirit, improving wellbeing, community engagement)?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ |

16.a. Please explain why you feel this way. *Optional*

17. How do you feel about the statement **'I believe that developing my awareness around NFM has had an impact on my mental health'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ |

17.a. Please explain the impact of NFM on your mental health? *Optional*

18. How do you feel about the statement **'I believe NFM has made me more resilient to the impact of flooding'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree | N/A |
|---|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

*18.a.* Please explain why you feel this way. *Optional*

*18.b.* How do you feel about the statement **'I believe NFM has made me more resilient in recovering from flooding'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree | N/A |
|---|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

*18.b.i.* Please explain why you feel this way. *Optional*

*19.* How do you feel about the statement **'I believe NFM has made my community more resilient to the impact of flooding'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree | N/A |
|---|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

*19.a.* Please explain why you feel this way. *Optional*

*19.b.* How do you feel about the statement **'I believe NFM has made my community more resilient in recovering from**

**flooding'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree | N/A |
|---|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

*19.b.i.* Please explain why you feel this way.

*20.* How do you feel about the statement '**I have confidence in the charities, local government, private companies and government agencies to manage NFM within Calderdale'?**

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | Completely agree | Agree | Neither agree nor disagree | Disagree | Completely disagree |
|---|---|---|---|---|---|
| Please select one | ☐ | ☐ | ☐ | ☐ | ☐ |

*20.a.* Please explain why you feel this way. *Optional*

*21.* What level of involvement in NFM do you wish from Government agency (e.g. Environment Agency), national charities (e.g. National Trust), private water companies (e.g. Yorkshire Water), local government (e.g local councils) and local community groups (e.g. Slow The Flow)? You can select more than one agency for each statement. *Optional*

Please don't select more than 5 answer(s) per row.

Please select between 1 and 8 answers.

Please don't select more than 8 answer(s) in any single column.

| | Government agency (e.g. Environment Agency) | Local government (e.g local councils) | Private water companies (e.g. Yorkshire water) | National charities (e.g National Trust) | Local community groups (e.g. Slow The Flow) |
|---|---|---|---|---|---|
| Planning the implementation of NFM | ☐ | ☐ | ☐ | ☐ | ☐ |

| | | | | | |
|---|---|---|---|---|---|
| Designing of NFM | | | | | |
| Funding for NFM | | | | | |
| Talking/getting in contact with landowners about the introduction of NFM on their property | | | | | |
| Implementing NFM in the catchment | | | | | |
| Monitoring and collecting data from NFM measures | | | | | |
| Upkeep of NFM measures | | | | | |
| Providing education on NFM measures | | | | | |

*21.a.* What do you feel is the government agency's (eg. Environment Agency) role in NFM projects?

*21.b.* What do you feel is the local government's (eg. local councils) role in NFM projects?

*21.c.* What do you feel is the role of national charities (eg. National Trust) in NFM projects?

*21.d.* What do you feel is the role of local community groups (eg. Slow The Flow) in NFM projects?

## Page 4: Secondary effects

22. Are you aware of any additional effects NFM may have other than flood reduction? These could be benefits or disadvantages.

Please select at least 1 answer(s).

- [ ] Yes
- [ ] No
- [ ] Not Sure

22.a. Can you list some of the effects that you know about?

## Page 5: Multiple benefits of NFM

*23.* Which potential benefits of NFM do you feel are most important? Definition of scientific terms can be found below. Please rank from 1-10 with 1 being the most important and 10 the least important.

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

| | 1 (most important) | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10(least important) |
|---|---|---|---|---|---|---|---|---|---|---|
| Reduced flood risk | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Improved water quality | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Habitat creation | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Increased biodiversity | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Resilient ecosystem | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Reduced erosion | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Sediment management | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Community spirit | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Greater connection to nature | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Carbon sequestration (storing carbon in plants) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Definitions of scientific terms used:

**Water quality** is measured by several factors, such as the concentration of dissolved oxygen, bacteria levels, the amount of salt (or salinity), or the amount of material suspended in the water (turbidity).

**Habitat** is the natural home or environment of an animal, plant, or other organism.

**Biodiversity** is the variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.

**Ecosystem** is the biological community of interacting organisms and their physical environment.

**Resilient ecosystem** is the capacity of an ecosystem to respond to a disturbance by resisting damage and recovering quickly.

**Erosion** is the action of surface processes that removes soil, rock, or dissolved material from one location on the Earth's crust, and then transports it to another location.

**Sediment** is solid material that is moved and deposited in a new location. Sediment can consist of rocks and minerals, as well as the remains of plants and animals.

**Carbon sequestration** is the long-term removal, capture or sequestration of carbon dioxide from the atmosphere to slow or reverse atmospheric CO2 pollution and to mitigate or reverse global warming.

*23.a.* Can you please explain why you have chosen this order of importance? *Optional*

*24.* Is there any other comment you wish to make in relation to NFM which has not been covered in this questionnaire?

## Page 6: Demographic questions

25. What is your age range? ✱ *Required*

- 18 - 25
- 26 - 35
- 36 - 45
- 46 - 55
- 56 - 65
- 66 - 75
- 76 - 85
- 86 +

26. What gender identity do you most identify with? ✱ *Required*

- Female
- Male
- Transgender Female
- Transgender Male
- Gender Variant/Non-Conforming
- Not listed (please specify below)
- Prefer not to say

26.a. If you selected not listed, please specify:

27. What is your employment status? ✱ *Required*

- Employed (full time),
- Employed (part-time)
- Unemployed
- Student
- Retired
- Self-employed
- Unable to work
- Would prefer not to say.

28. What is the highest level of education you have achieved? (if you are currently studying please choose the highest level of education you have received) * *Required*

- GCSE/O level or equivalent
- A level or equivalent
- Bachelor's degree or equivalent (eg. BA, BSc)
- Master's degree or equivalent (eg. MA, MSc, Med)
- Doctorate or equivalent (eg. PhD, EdD)
- Would prefer not to say/NA
- Other (please specify)

28.a. If you selected Other, please specify:

29. Please select which village/town you reside in.

- Hebden Bridge
- Mytholmroyd
- Todmonden
- Other (please specify)

29.a. If you selected Other, please specify:

30. What is/ was your occupation? (if you are not able to work, prefer not to say or do not want to answer this question please skip this question)

- Public sector - Environment
- Public sector- Local Government
- Private sector - Environment
- Private sector - Other
- Charity sector - Environment
- Charity sector - Other
- Academic
- Farming
- Other

31. Would you like to be involved in a follow-up phone/online interview in relation to this questionnaire? * *Required*

- Yes
- No
- Not sure/I want to know more

31.a. Please provide contact information such as an email or phone number to allow the researcher to contact you to arrange the interview

If you would like to know more or have questions about the interview process, please email Sophie at gysjt@leeds.ac.uk.

## Page 7: Final page

Thank you for taking the time to complete this questionnaire. If you have any further questions about this study, please email the researcher, Sophie Tankard (gysjt@leeds.ac.uk), or supervisor, Megan Klaar (M.J.Klaar@leeds.ac.uk).

# Appendix B

Hydrograph analysis

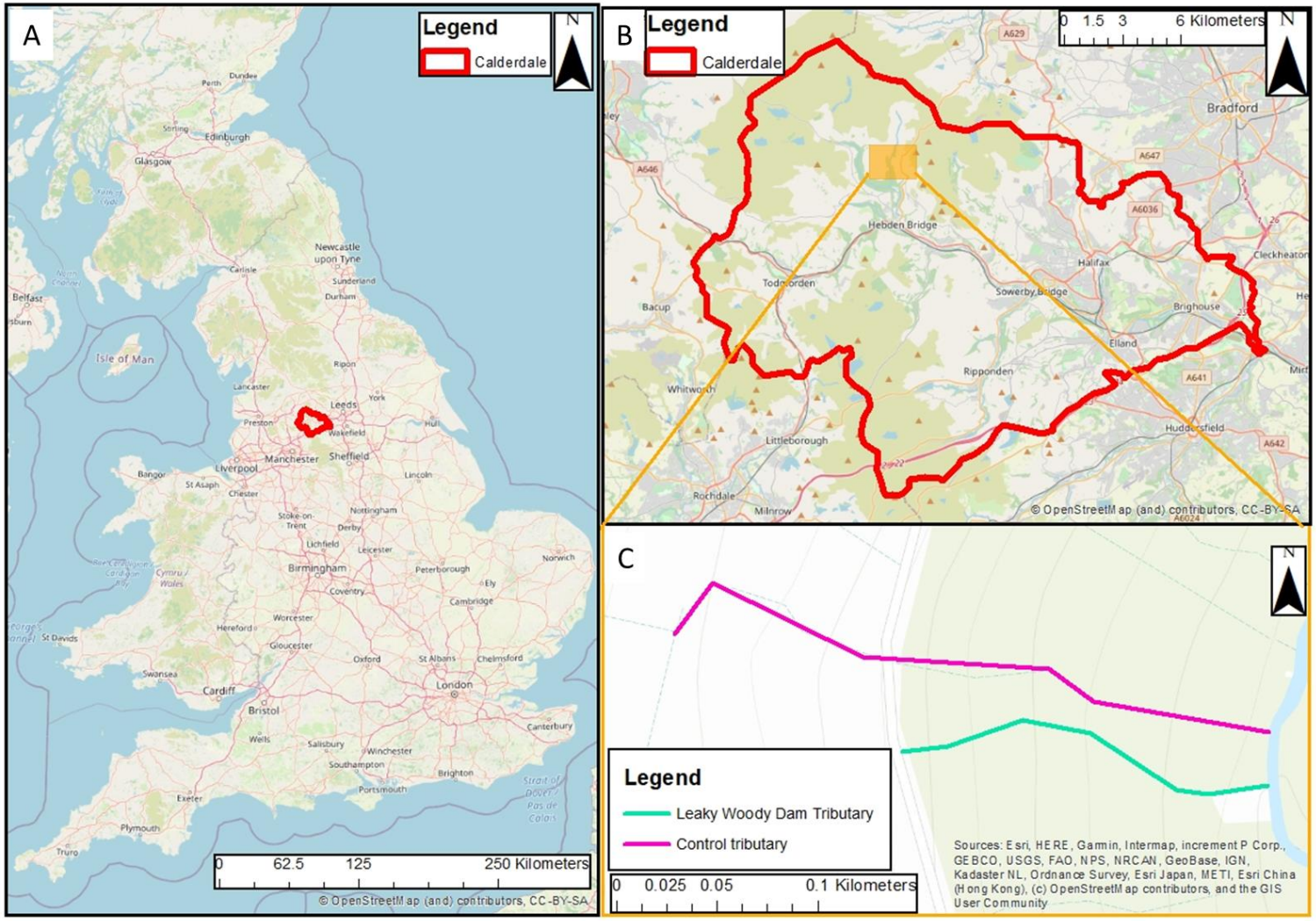
A
Legend
Calderdale
N
Edinburgh
Glasgow
Newcastle upon Tyne
Sunderland
Durham
Isle of Man
Ripon
Lancaster
Leeds
York
Preston
Wakefield
Hull
Manchester
Sheffield
Liverpool
Bangor
St Asaph
Chester
Lincoln
Nottingham
Stoke-on-Trent
Derby
Lichfield
Leicester
Norwich
Birmingham
Peterborough
Ely
Coventry
Cambridge
Worcester
Hereford
St Davids
Gloucester
Oxford
St Albans
Chelmsford
Swansea
Cardiff
London
Bristol
Canterbury
Wells
Salisbury
Winchester
Southampton
Brighton
Portsmouth
Exeter
Plymouth
Truro
0 62.5 125 250 Kilometers
© OpenStreetMap (and) contributors, CC-BY-SA
B
Legend
Calderdale
0 1.5 3 6 Kilometers
N
Bradford
Hebden Bridge
Todmorden
Halifax
Sowerby Bridge
Brighouse
Elland
Ripponden
Whitworth
Littleborough
Rochdale
Milnrow
Huddersfield
Cleckheaton
© OpenStreetMap (and) contributors, CC-BY-SA
C
N
Legend
Leaky Woody Dam Tributary
Control tributary
0 0.025 0.05 0.1 Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure B.1 – A locational map of the loggers placement within the two tributaries

Figure B.2 – An example of increased sedimentation behind the V-Notch weirs

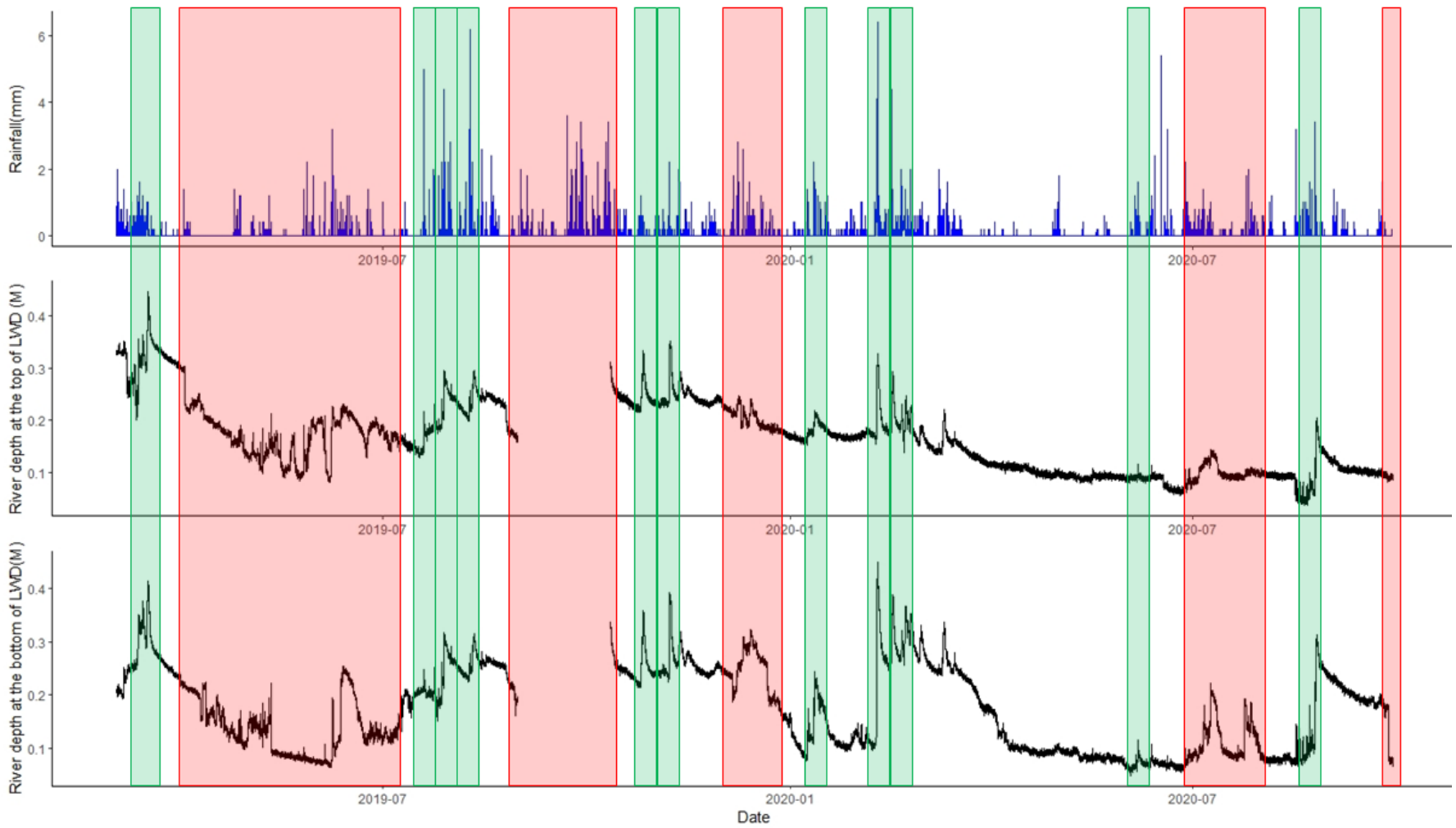


Figure B.3 - The full hydrograph record with events selected for further analysis coded in green and periods of data inconsistencies highlighted in red.

Table B.1 – Return periods of over 1 year between 1978 and 2020

| Date | Rainfall | Rank | Probability | T | Reoccurrence interval |
|---|---|---|---|---|---|
| 26/12/2015 | 79.8 | 1 | 0.013497 | 74.09 | 34 |
| 09/02/2020 | 66.8 | 2 | 0.026994 | 37.045 | 17 |
| 22/06/2012 | 63.8 | 3 | 0.040491 | 24.69667 | 11.33333 |
| 30/10/2000 | 51.4 | 4 | 0.053988 | 18.5225 | 8.5 |
| 11/02/2001 | 49.4 | 5 | 0.067485 | 14.818 | 6.8 |
| 25/08/2012 | 49.2 | 6 | 0.080983 | 12.34833 | 5.666667 |
| 10/08/2004 | 48 | 7 | 0.09448 | 10.58429 | 4.857143 |
| 24/11/1996 | 45.6 | 8 | 0.107977 | 9.26125 | 4.25 |
| 25/08/2020 | 45.2 | 9 | 0.121474 | 8.232222 | 3.777778 |
| 16/03/2019 | 43 | 10 | 0.134971 | 7.409 | 3.4 |
| 07/05/1999 | 42.4 | 11 | 0.148468 | 6.735455 | 3.090909 |
| 21/01/2008 | 41.2 | 12 | 0.161965 | 6.174167 | 2.833333 |
| 26/06/1989 | 41.2 | 13 | 0.175462 | 5.699231 | 2.615385 |
| 23/06/2004 | 40.2 | 14 | 0.188959 | 5.292143 | 2.428571 |
| 06/03/1998 | 39.8 | 15 | 0.202456 | 4.939333 | 2.266667 |
| 04/11/2010 | 39.8 | 16 | 0.215954 | 4.630625 | 2.125 |
| 21/12/1991 | 39.4 | 17 | 0.229451 | 4.358235 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| 25/12/2015 | 39.2 | 18 | 0.242948 | 4.116111 | 1.888889 |
| 17/07/2009 | 39 | 19 | 0.256445 | 3.899474 | 1.789474 |
| 18/12/2014 | 38.8 | 20 | 0.269942 | 3.7045 | 1.7 |
| 11/08/2003 | 38.4 | 21 | 0.283439 | 3.528095 | 1.619048 |
| 12/09/1993 | 37.8 | 22 | 0.296936 | 3.367727 | 1.545455 |
| 24/10/2005 | 37.8 | 23 | 0.310433 | 3.221304 | 1.478261 |
| 01/11/2009 | 37 | 24 | 0.32393 | 3.087083 | 1.416667 |
| 02/04/2018 | 37 | 25 | 0.337427 | 2.9636 | 1.36 |
| 26/03/1987 | 36.8 | 26 | 0.350925 | 2.849615 | 1.307692 |
| 30/06/1989 | 36.6 | 27 | 0.364422 | 2.744074 | 1.259259 |
| 02/12/1999 | 36.6 | 28 | 0.377919 | 2.646071 | 1.214286 |
| 30/06/2003 | 36.6 | 29 | 0.391416 | 2.554828 | 1.172414 |
| 25/09/2012 | 36.6 | 30 | 0.404913 | 2.469667 | 1.133333 |
| 28/07/2019 | 36.4 | 31 | 0.41841 | 2.39 | 1.096774 |
| 12/12/2015 | 36.2 | 32 | 0.431907 | 2.315313 | 1.0625 |
| 19/09/1999 | 36 | 33 | 0.445404 | 2.245152 | 1.030303 |
| 01/10/1999 | 36 | 34 | 0.458901 | 2.179118 | 1 |

| Group | Group.2 | Rainfall Du | Total rainfa | Mean (mm | Peak rain | Peak rainfall time | Total rainfa | Total rainfa | Date and Time sta | Initial deptl | Time betw | Time at peak | Peak deptl | Date and time at e | Depth 12 h | Depth 24h | Peak vs 24 | Peak rainfa | diference i | Dif in intial | Start of rai |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 14.25 | 21.8 | 1.529825 | 1.2 | 12/03/2019 07:00 | 25 | 9.8 | 11/03/2019 22:00 | 0.206 | 14.03 | 12/03/2019 12:00 | 0.358 | 13/03/2019 00:10 | 0.319667 | 0.316 | 0.042 | 5 | 152 | 0.11 | 1 |
| A | 1 | 14.25 | 21.8 | 1.529825 | 1.2 | 12/03/2019 07:00 | 25 | 9.8 | 11/03/2019 22:00 | 0.257667 | 16.16 | 12/03/2019 14:10 | 0.352 | 13/03/2019 07:02 | 0.333333 | 0.316667 | 0.035333 | 7.16 | 94.3333 | 0.059 | 1 |
| A | 1 | 26.5 | 45 | 1.698113 | 1 | 16/03/2019 09:30 | 32.2 | 6 | 16/03/2019 04:14 | 0.300667 | 17.23 | 16/03/2019 22:02 | 0.445 | 23/03/2019 00:00 | 0.402 | 0.368333 | 0.076667 | 12.53 | 144.3333 | 0.067667 | 3.75 |
| A | 1 | 26.5 | 45 | 1.698113 | 1 | 16/03/2019 09:30 | 32.2 | 6 | 16/03/2019 04:14 | 0.295 | 18.83 | 16/03/2019 23:08 | 0.416333 | 23/03/2019 00:00 | 0.365667 | 0.312333 | 0.104 | 13.63 | 121.3333 | 0.017333 | 3.75 |
| B | 2 | 40.5 | 81.8 | 2.019753 | 6.4 | 09/02/2020 10:45 | 1.6 | 1.6 | 08/02/2020 23:30 | 0.164667 | 11.75 | 09/02/2020 11:15 | 0.325 | 13/02/2020 00:00 | 0.301333 | 0.255 | 0.07 | 0.5 | 160.3333 | 0.090333 | 5 |
| B | 2 | 40.5 | 81.8 | 2.019753 | 6.4 | 09/02/2020 10:45 | 1.6 | 1.6 | 08/02/2020 23:30 | 0.121475 | 11.75 | 09/02/2020 11:15 | 0.447129 | 13/02/2020 00:00 | 0.397723 | 0.356643 | 0.090486 | 0.5 | 325.6541 | 0.235168 | 5 |
| B | 2 | 9.5 | 16.2 | 1.705263 | 1.6 | 06/06/2020 05:45 | 9 | 4.8 | 05/06/2020 23:30 | 0.083667 | 6.75 | 06/06/2020 06:45 | 0.114 | 06/06/2020 12:00 | 0.092667 | 0.093333 | 0.020667 | 1 | 30.33333 | 0.009667 | 2.25 |
| B | 2 | 9.5 | 16.2 | 1.705263 | 1.6 | 06/06/2020 05:45 | 9 | 4.8 | 05/06/2020 23:30 | 0.061667 | 6.75 | 06/06/2020 06:45 | 0.113667 | 06/06/2020 12:00 | 0.088 | 0.083 | 0.030667 | 1 | 52 | 0.021333 | 2.25 |
| C | 3 | 15.75 | 33.8 | 2.146032 | 2.2 | 07/11/2019 13:30 | 9 | 2 | 07/11/2019 03:00 | 0.231333 | 20 | 07/11/2019 23:00 | 0.351667 | 10/11/2019 12:00 | 0.306 | 0.271333 | 0.080333 | 9.5 | 120.3334 | 0.04 | 2.5 |
| C | 3 | 15.75 | 33.8 | 2.146032 | 2.2 | 07/11/2019 13:30 | 9 | 2 | 07/11/2019 03:00 | 0.227217 | 19.25 | 07/11/2019 22:15 | 0.38753 | 10/11/2019 12:00 | 0.333639 | 0.292185 | 0.095345 | 8.75 | 160.3126 | 0.064968 | 2.5 |
| B | 2 | 25 | 39.8 | 1.592 | 1.2 | 25/10/2019 14:15 | 3.4 | 3.2 | 26/10/2019 10:45 | 0.283667 | 7.25 | 26/10/2019 18:00 | 0.330333 | 30/10/2019 12:00 | 0.286667 | 0.267667 | 0.062667 | 3.75 | 46.6666 | -0.01233 | 23.75 |
| B | 2 | 25 | 39.8 | 1.592 | 1.2 | 25/10/2019 14:15 | 3.4 | 3.2 | 26/10/2019 10:45 | 0.307238 | 7.25 | 26/10/2019 18:00 | 0.358342 | 30/10/2019 12:00 | 0.310941 | 0.283113 | 0.075229 | 3.75 | 51.1043 | -0.01505 | 23.75 |
| C | 3 | 20.25 | 31 | 1.530864 | 2 | 11/11/2019 14:15 | 0.8 | 0.2 | 11/11/2019 11:45 | 0.243333 | 2.25 | 12/11/2019 14:00 | 0.294 | 14/11/2019 17:15 | 0.263333 | 0.294 | 0 | 23.75 | 50.6667 | 0.129333 | 13.5 |
| C | 3 | 20.25 | 31 | 1.530864 | 2 | 11/11/2019 14:15 | 0.8 | 0.2 | 11/11/2019 11:45 | 0.260177 | 1.5 | 12/11/2019 13:15 | 0.317499 | 14/11/2019 17:15 | 0.284336 | 0.317499 | 0 | 23 | 57.3225 | 0.196025 | 13.5 |
| A | 1 | 8.25 | 22.6 | 2.739394 | 3.2 | 09/08/2019 05:00 | 7.2 | 0 | 09/08/2019 06:00 | 0.219333 | 1 | 09/08/2019 07:00 | 0.248667 | 10/08/2019 00:00 | 0.220667 | 0.228333 | 0.020333 | 2 | 29.33337 | 0.009 | 5.25 |
| A | 1 | 8.25 | 22.6 | 2.739394 | 3.2 | 10/08/2019 05:00 | 7.2 | 0 | 09/08/2019 06:00 | 0.242667 | 1.25 | 09/08/2019 07:15 | 0.274667 | 10/08/2019 00:00 | 0.245333 | 0.249 | 0.025667 | 2.25 | 31.99997 | 0.006333 | 5.25 |
| C | 3 | 16.75 | 21.4 | 1.277612 | 2.2 | 10/08/2019 11:45 | 38.6 | 32 | 10/08/2019 11:45 | 0.227 | 21.5 | 11/08/2019 09:15 | 0.293333 | 13/08/2019 18:00 | 0.274333 | 0.293333 | -3.33E-08 | 21.5 | 66.3333 | 0.066333 | 11.75 |
| C | 3 | 16.75 | 21.4 | 1.277612 | 2.2 | 10/08/2019 11:45 | 38.6 | 32 | 10/08/2019 11:45 | 0.251 | 20.25 | 11/08/2019 08:00 | 0.313667 | 13/08/2019 18:00 | 0.284333 | 0.313667 | 3.33E-08 | 20.25 | 62.6667 | 0.062667 | 11.75 |
| A | 1 | 23 | 48 | 2.086957 | 4.4 | 15/02/2020 19:00 | 11.8 | 2 | 15/02/2020 16:45 | 0.182333 | 9.75 | 16/02/2020 09:30 | 0.287 | 19/08/2020 00:00 | 0.260333 | 0.301971 | -0.01497 | 14.5 | 104.6667 | 0.119638 | 7.75 |
| A | 1 | 23 | 48 | 2.086957 | 4.4 | 15/02/2020 19:00 | 11.8 | 2 | 15/02/2020 16:45 | 0.268128 | 12 | 16/02/2020 11:45 | 0.386035 | 19/08/2020 00:00 | 0.248 | 0.300102 | 0.085933 | 16.75 | 117.9069 | 0.031974 | 7.75 |
| A | 1 | 6 | 7.2 | 1.2 | 1.4 | 19/07/2019 10:45 | 0.8 | 0 | 19/07/2019 08:45 | 0.148 | 3.5 | 19/07/2019 12:15 | 0.180667 | 19/07/2019 16:30 | 0.178 | 0.176333 | 0.004333 | 1.5 | 32.6667 | 0.028333 | 2 |
| A | 1 | 6 | 7.2 | 1.2 | 1.4 | 19/07/2019 10:45 | 0.8 | 0 | 19/07/2019 08:45 | 0.210333 | 3.75 | 19/07/2019 12:30 | 0.223333 | 19/07/2019 16:30 | 0.217333 | 0.201 | 0.022333 | 1.75 | 13 | -0.00933 | 2 |
| B | 2 | 8.5 | 12.4 | 1.458824 | 2.2 | 19/07/2019 15:45 | 8 | 7.2 | 19/07/2019 16:30 | 0.154 | 1.75 | 19/07/2019 18:15 | 0.214667 | 20/07/2019 00:00 | 0.174667 | 0.173333 | 0.041333 | 2.5 | 60.6667 | 0.019333 | 1 |
| B | 2 | 8.5 | 12.4 | 1.458824 | 2.2 | 19/07/2019 15:45 | 8 | 7.2 | 19/07/2019 16:30 | 0.216 | 1.75 | 19/07/2019 18:15 | 0.246667 | 20/07/2019 00:00 | 0.215667 | 0.197333 | 0.049333 | 2.5 | 30.6667 | -0.01867 | 1 |
| C | 3 | 3.25 | 5 | 1.538462 | 1.4 | 21/07/2019 22:45 | 22 | 0 | 22/07/2019 15:15 | 0.178 | 8.75 | 22/07/2019 01:00 | 0.192333 | 22/07/2019 12:00 | 0.179333 | 0.185 | 0.007333 | 2.25 | 14.3333 | 0.007 | 18 |
| C | 3 | 3.25 | 5 | 1.538462 | 1.4 | 21/07/2019 22:45 | 22 | 0 | 22/07/2019 15:15 | 0.198667 | 8 | 22/07/2019 00:15 | 0.213667 | 22/07/2019 12:00 | 0.199 | 0.206 | 0.007667 | 1.5 | 15 | 0.007333 | 18 |
| A | 1 | 2.5 | 11.8 | 4.72 | 2 | 24/07/2019 01:45 | 7.4 | 0 | 24/07/2019 02:30 | 0.190333 | 2 | 24/07/2019 04:30 | 0.230667 | 25/07/2019 18:30 | 0.195667 | 0.195333 | 0.035333 | 2.75 | 40.3334 | 0.005 | 0.75 |
| A | 1 | 2.5 | 11.8 | 4.72 | 2 | 24/07/2019 01:45 | 7.4 | 0 | 24/07/2019 02:30 | 0.203667 | 2.25 | 24/07/2019 04:45 | 0.245667 | 25/07/2019 18:30 | 0.196 | 0.192667 | 0.053 | 3 | 42 | -0.011 | 0.75 |
| B | 2 | 7.5 | 17.6 | 2.346667 | 2.2 | 27/07/2019 13:15 | 5.4 | 1.2 | 27/07/2019 12:45 | 0.187667 | 5.75 | 27/07/2019 18:30 | 0.240667 | 28/07/2019 00:00 | 0.207667 | 0.221333 | 0.019333 | 5.25 | 53 | 0.033667 | 1.25 |
| B | 2 | 7.5 | 17.6 | 2.346667 | 2.2 | 27/07/2019 13:15 | 5.4 | 1.2 | 27/07/2019 12:45 | 0.188 | 5.75 | 27/07/2019 18:30 | 0.258333 | 28/07/2019 00:00 | 0.221333 | 0.234 | 0.024333 | 5.25 | 70.3333 | 0.046 | 1.25 |
| A | 1 | 15 | 35.2 | 2.933333 | 2.6 | 28/07/2019 18:15 | 29.6 | 15.2 | 28/07/2019 17:30 | 0.209667 | 2 | 28/07/2019 19:30 | 0.29 | 31/07/2019 00:00 | 0.276 | 0.271333 | 0.018667 | 1.25 | 80.3333 | 0.061667 | 1.75 |
| A | 1 | 15 | 35.2 | 2.933333 | 2.6 | 28/07/2019 18:15 | 29.6 | 15.2 | 28/07/2019 17:30 | 0.219667 | 2.25 | 28/07/2019 19:45 | 0.314 | 31/07/2019 00:00 | 0.295 | 0.292667 | 0.021333 | 1.5 | 94.3333 | 0.073 | 1.75 |
| B | 2 | 10.25 | 9.8 | 0.933333 | 2.8 | 31/07/2019 10:00 | 49.2 | 13.2 | 31/07/2019 20:00 | 0.257333 | 2.5 | 31/07/2019 20:30 | 0.262667 | 02/08/2019 10:30 | 0.249667 | 0.241 | 0.021667 | 10.5 | 5.3334 | -0.01633 | 10.75 |
| B | 2 | 10.25 | 9.8 | 0.933333 | 2.8 | 31/07/2019 10:00 | 49.2 | 13.2 | 31/07/2019 20:00 | 0.274 | 0.5 | 31/07/2019 20:30 | 0.286333 | 02/08/2019 10:30 | 0.273333 | 0.264667 | 0.021667 | 10.5 | 12.3333 | -0.00933 | 10.75 |
| A | 1 | 8.75 | 16.8 | 1.92 | 2.2 | 11/01/2020 17:45 | 20.2 | 0 | 11/01/2020 16:15 | 0.176 | 9.5 | 12/01/2020 01:45 | 0.217667 | 14/01/2020 00:00 | 0.208 | 0.209667 | 0.008 | 8 | 41.6667 | 0.033667 | 0.5 |
| A | 1 | 8.75 | 16.8 | 1.92 | 2.2 | 11/01/2020 17:45 | 20.2 | 0 | 11/01/2020 16:15 | 0.114509 | 9.75 | 12/01/2020 02:00 | 0.242134 | 14/01/2020 00:00 | 0.218451 | 0.22528 | 0.016854 | 8.25 | 127.6249 | 0.110771 | 0.5 |
| A | 1 | 14 | 48.8 | 3.485714 | 3.4 | 25/08/2020 07:30 | 15.2 | 0 | 44068.30208 | 0.08 | 16 | 44068.98958 | 0.205 | 28/08/2020 00:00 | 0.184 | 0.166 | 0.039 | 16.25 | 125 | 0.086 | 4.25 |
| A | 1 | 14 | 48.8 | 3.485714 | 3.4 | 25/08/2020 07:30 | 15.2 | 0 | 44068.30208 | 0.14 | 16.5 | 44069.01042 | 0.313 | 28/08/2020 00:00 | 0.297 | 0.278 | 0.035 | 16.75 | 173 | 0.138 | 4.25 |

Figure B.4 – Collected variables and events for hydrographic analysis

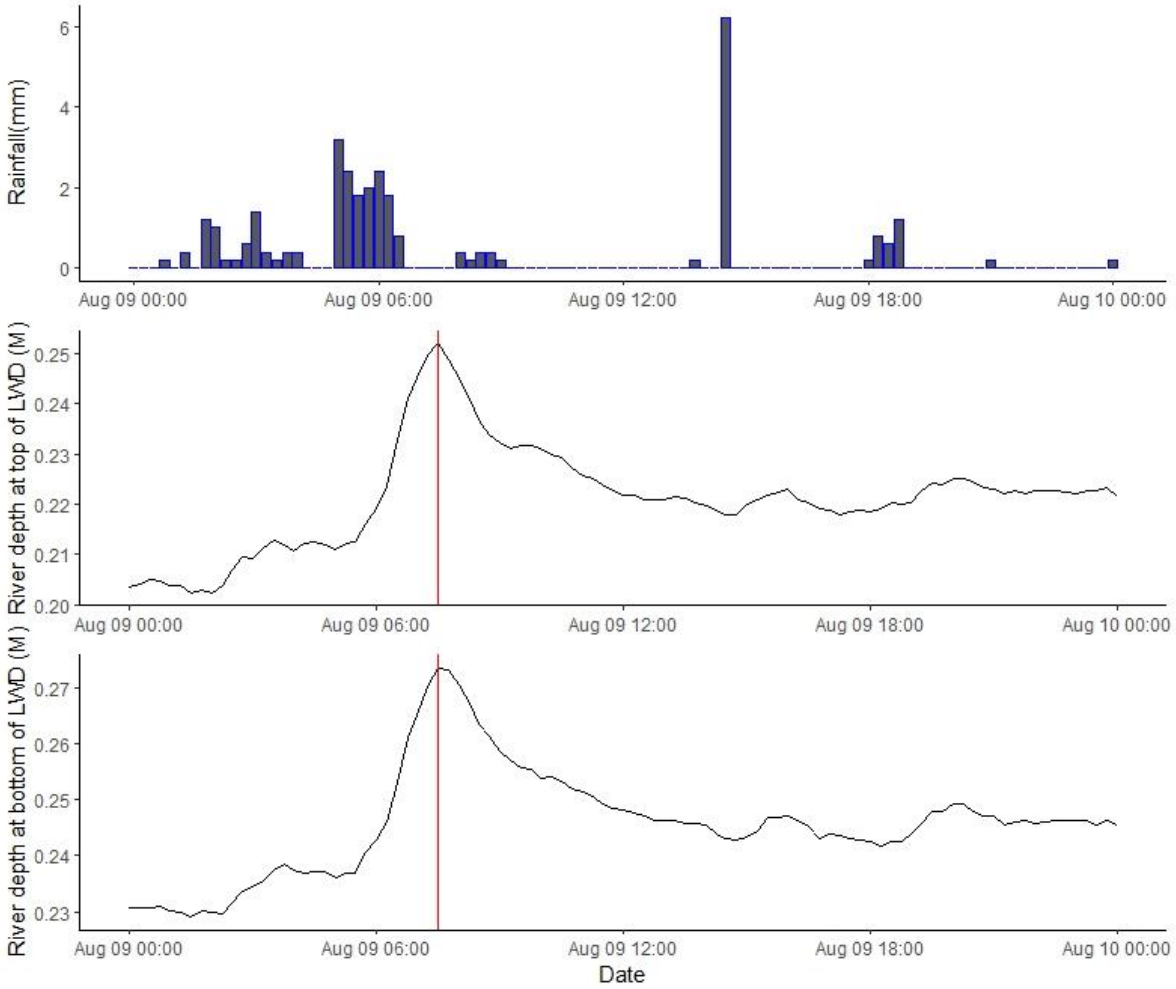


Figure B.5 - A hydrograph of rainfall and river depth record during the 9th August 2019 group A event. The red line indicates the peak of the hydrograph.

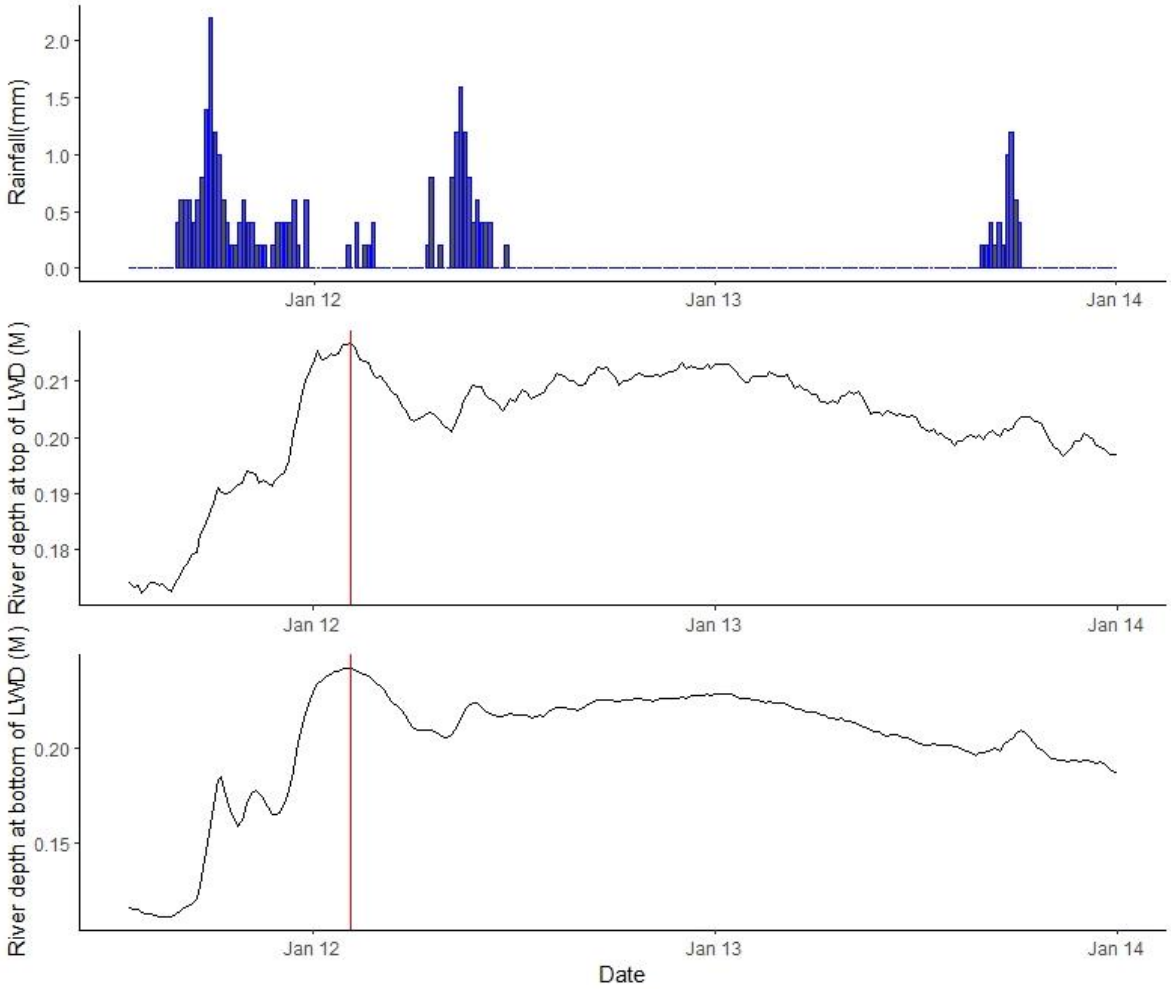


Figure B.6 - A hydrograph of rainfall and river depth record during the 11th January 2020 group A event. The red line indicates the peak of the hydrograph.

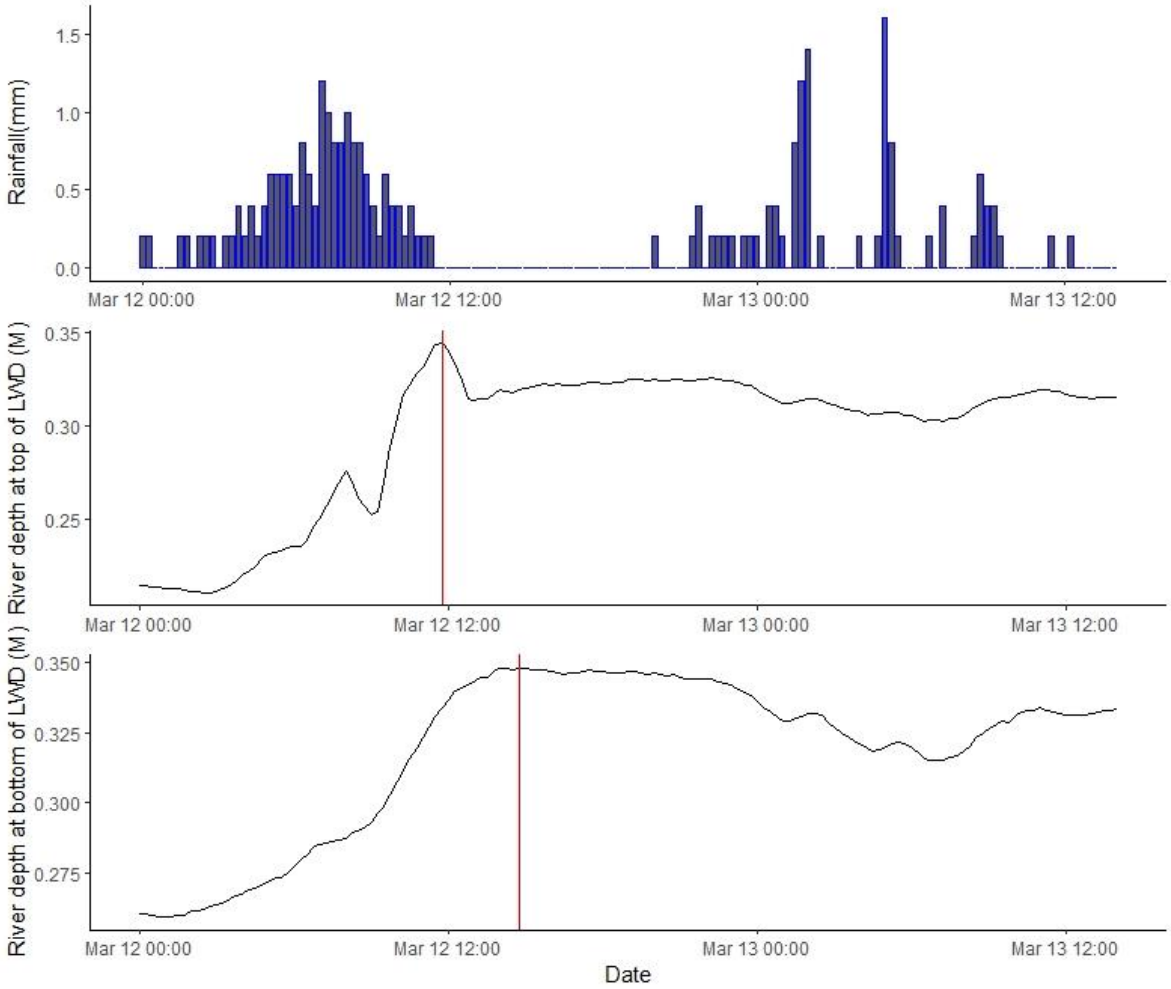


Figure B.7 - A hydrograph of rainfall and river depth record during the 12th March 2019 group A event. The red line indicates the peak of the hydrograph.

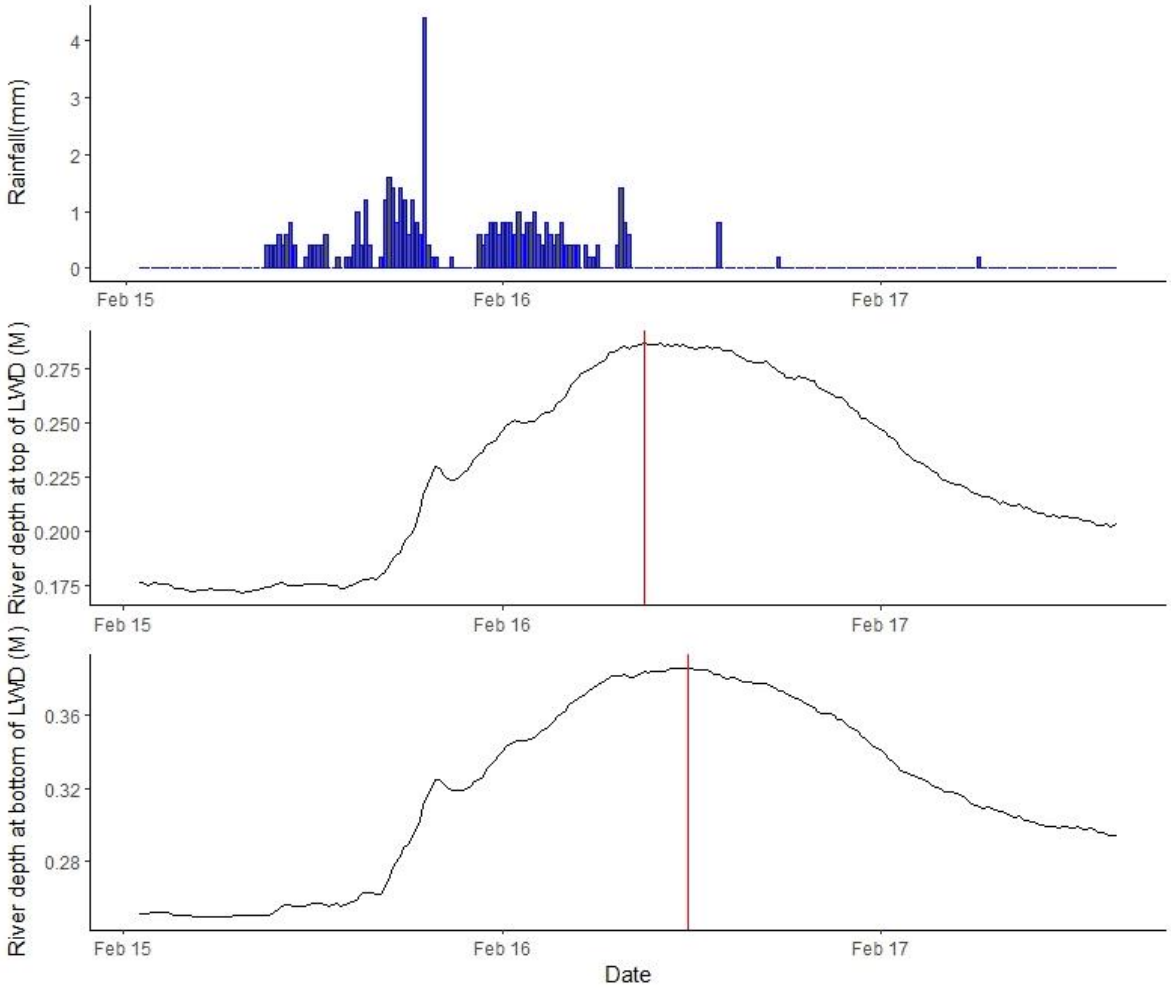


Figure B.8 - A hydrograph of rainfall and river depth record during the 15th February 2020 group A event. The red line indicates the peak of the hydrograph.

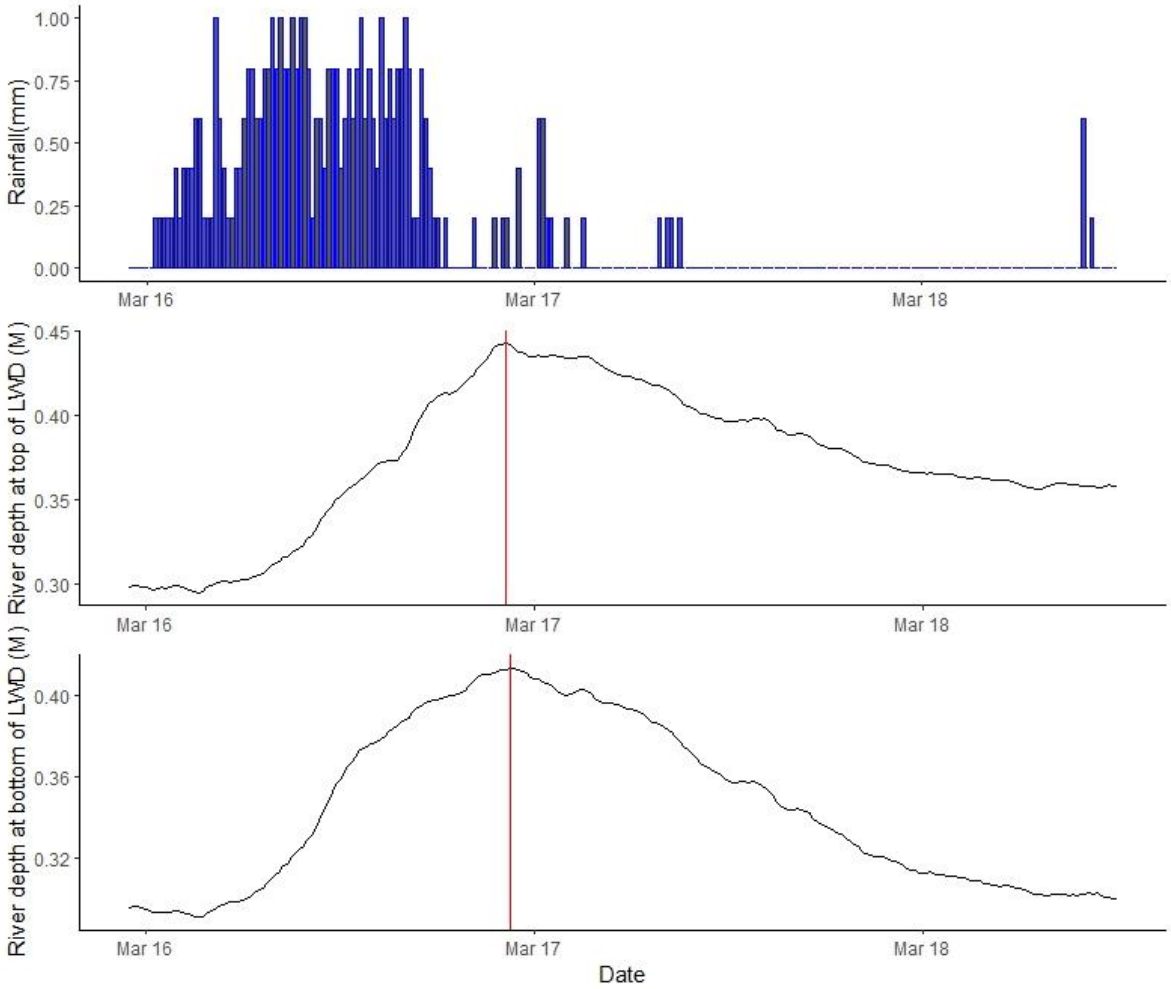


Figure B.9 - A hydrograph of rainfall and river depth record during the 16th March 2019 group A event. The red line indicates the peak of the hydrograph.

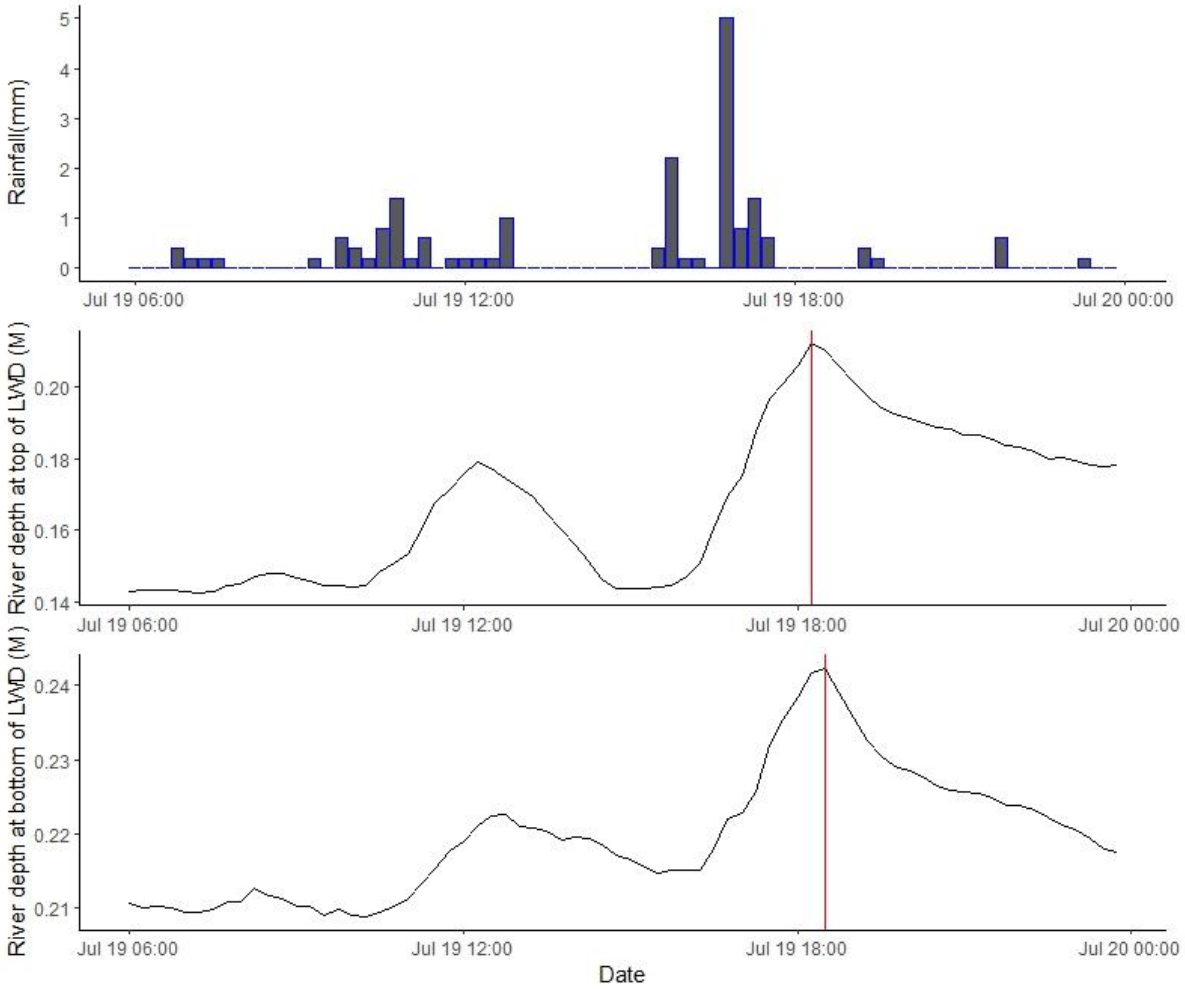


Figure B.10- A hydrograph of rainfall and river depth record during the 19th July 2019 group A event. The red line indicates the peak of the hydrograph.

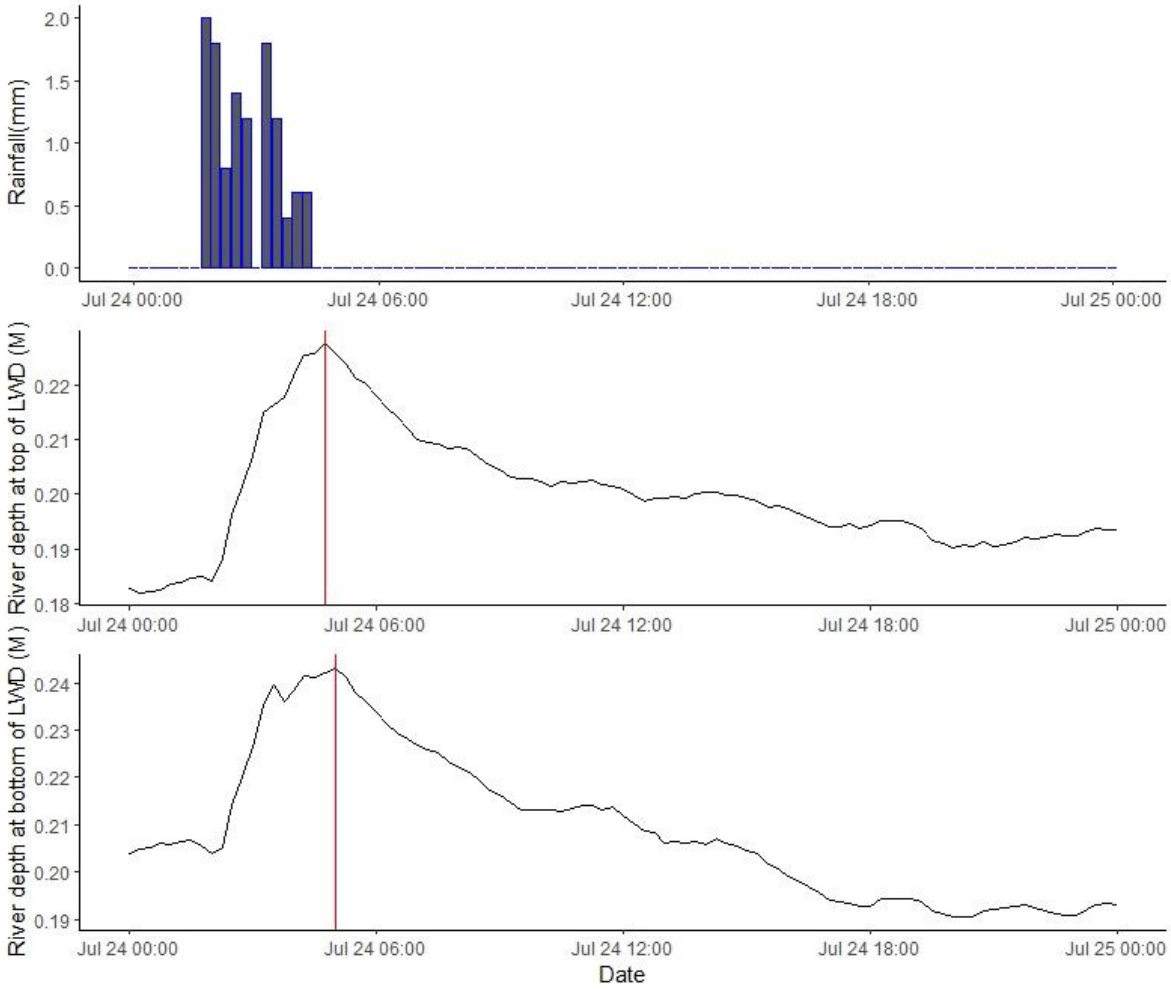


Figure B.11- A hydrograph of rainfall and river depth record during the 24th July 2019 group A event. The red line indicates the peak of the hydrograph.

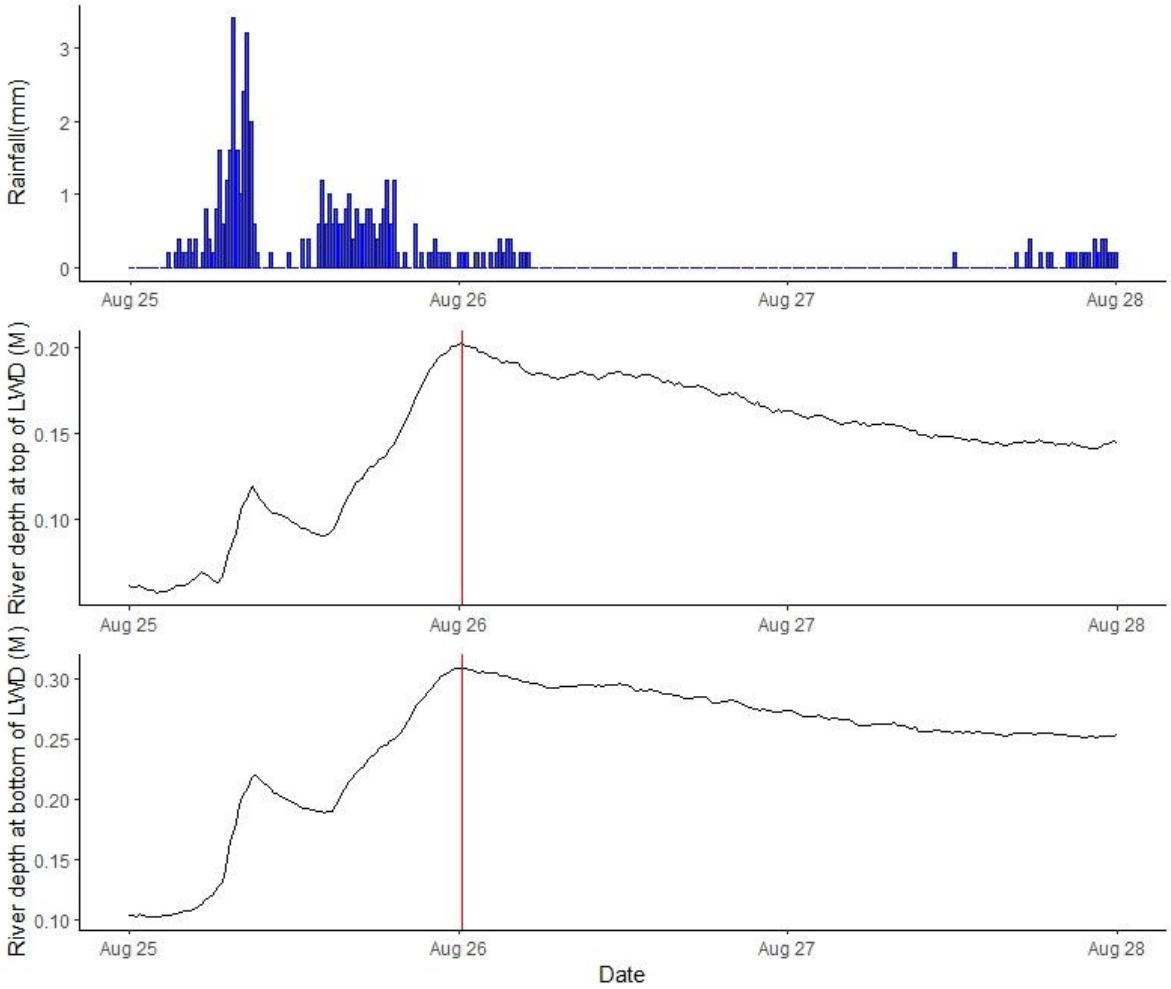


Figure B.12- A hydrograph of rainfall and river depth record during the 25th August 2020 group A event. The red line indicates the peak of the hydrograph.

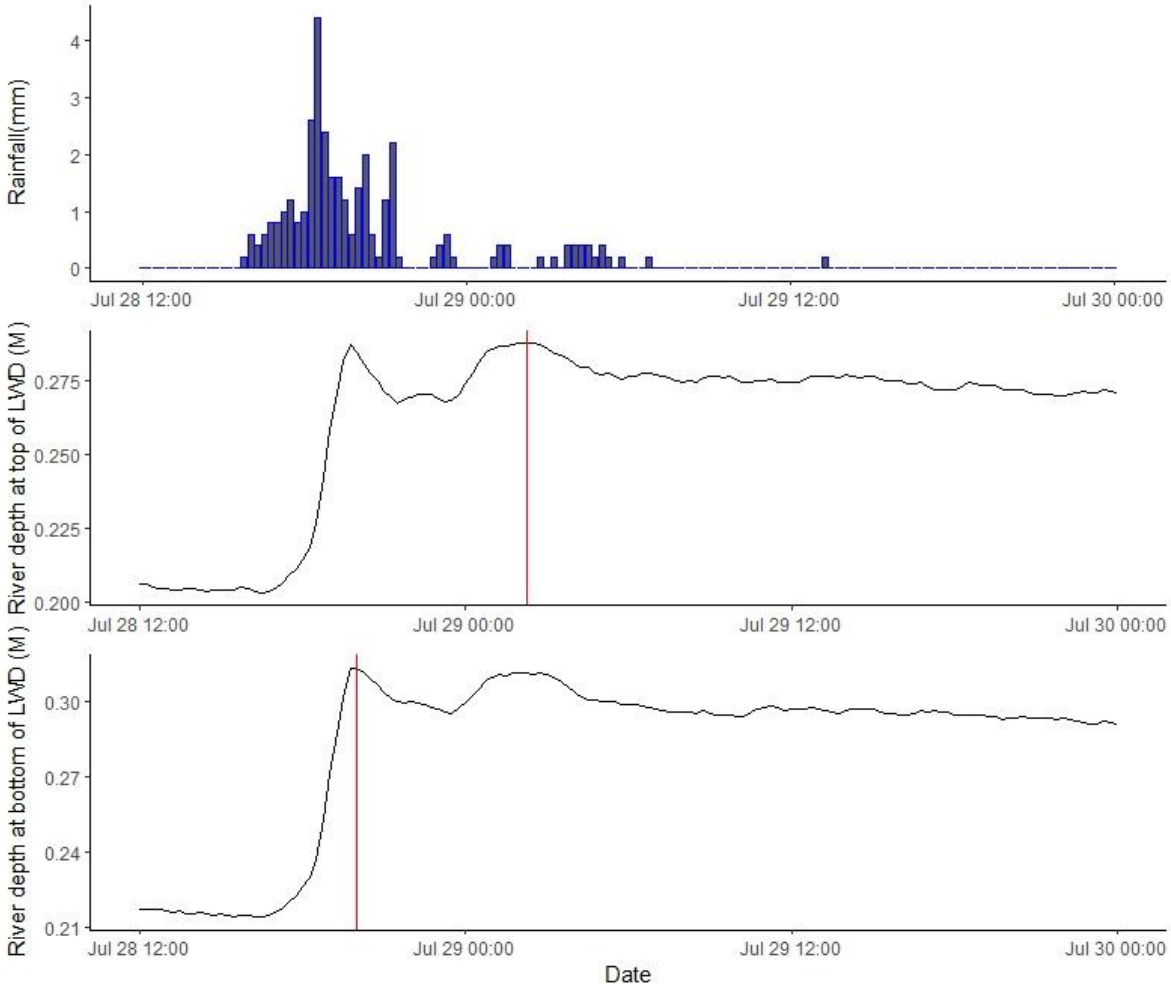


Figure B.13- A hydrograph of rainfall and river depth record during the 28th July 2019 group A event. The red line indicates the peak of the hydrograph.

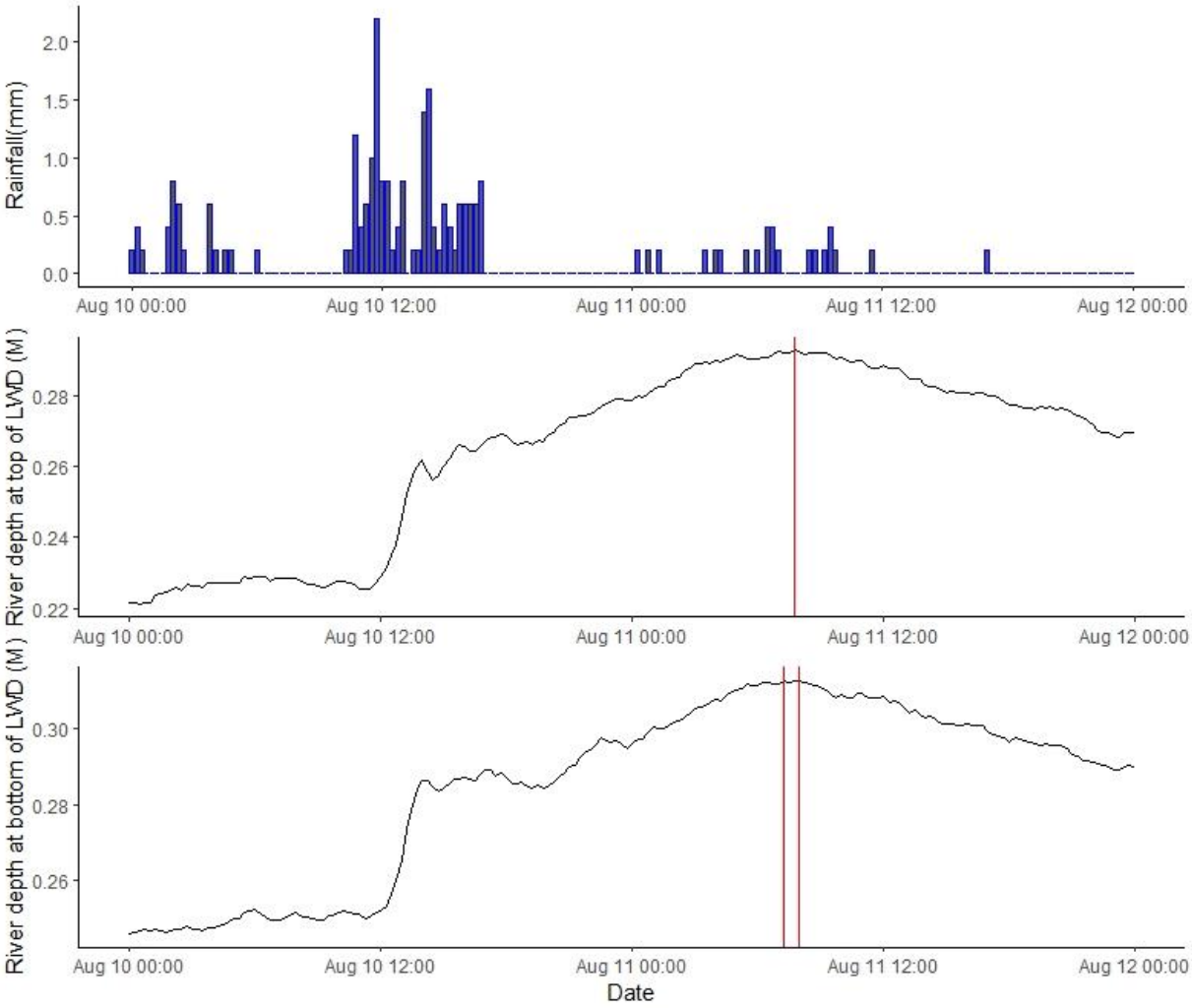


Figure B.14- A hydrograph of rainfall and river depth record during the 10th August 2019 group C event. The red line indicates the peak of the hydrograph.

Table B.2 - The table states the time and date the peak depth (m) recorded at the top and bottom of the leaky wood dam with a rolling average window of 3 and 5.The peak depth recorded is highlighted in blue.

| Date and Time (D/M/Y H:M) | Top of LWD (m) | Top of LWD Rolling average 3 (m) | Top of LWD Rolling average 5 (m) | Bottom of LWD (m) | Bottom of LWD Rolling average 3 (m) | Bottom of LWD Rolling average 5 (m) |
|---|---|---|---|---|---|---|
| 11/08/2019 6:45 | 0.294 | 0.2916667 | 0.2916 | 0.316 | 0.3123333 | 0.3120 |
| 11/08/2019 7:15 | 0.294 | 0.2920000 | 0.2922 | 0.312 | 0.3113333 | 0.3130 |
| 11/08/2019 7:45 | 0.291 | 0.2923333 | 0.2930 | 0.315 | 0.3130000 | 0.3128 |
| 11/08/2019 8:00 | 0.293 | 0.2926667 | 0.2924 | 0.313 | 0.3136667 | 0.3130 |
| 11/08/2019 9:15 | 0.292 | 0.2933333 | 0.2922 | 0.311 | 0.3110000 | 0.3102 |
| 11/08/2019 9:30 | 0.295 | 0.2926667 | 0.2912 | 0.309 | 0.3096667 | 0.3092 |

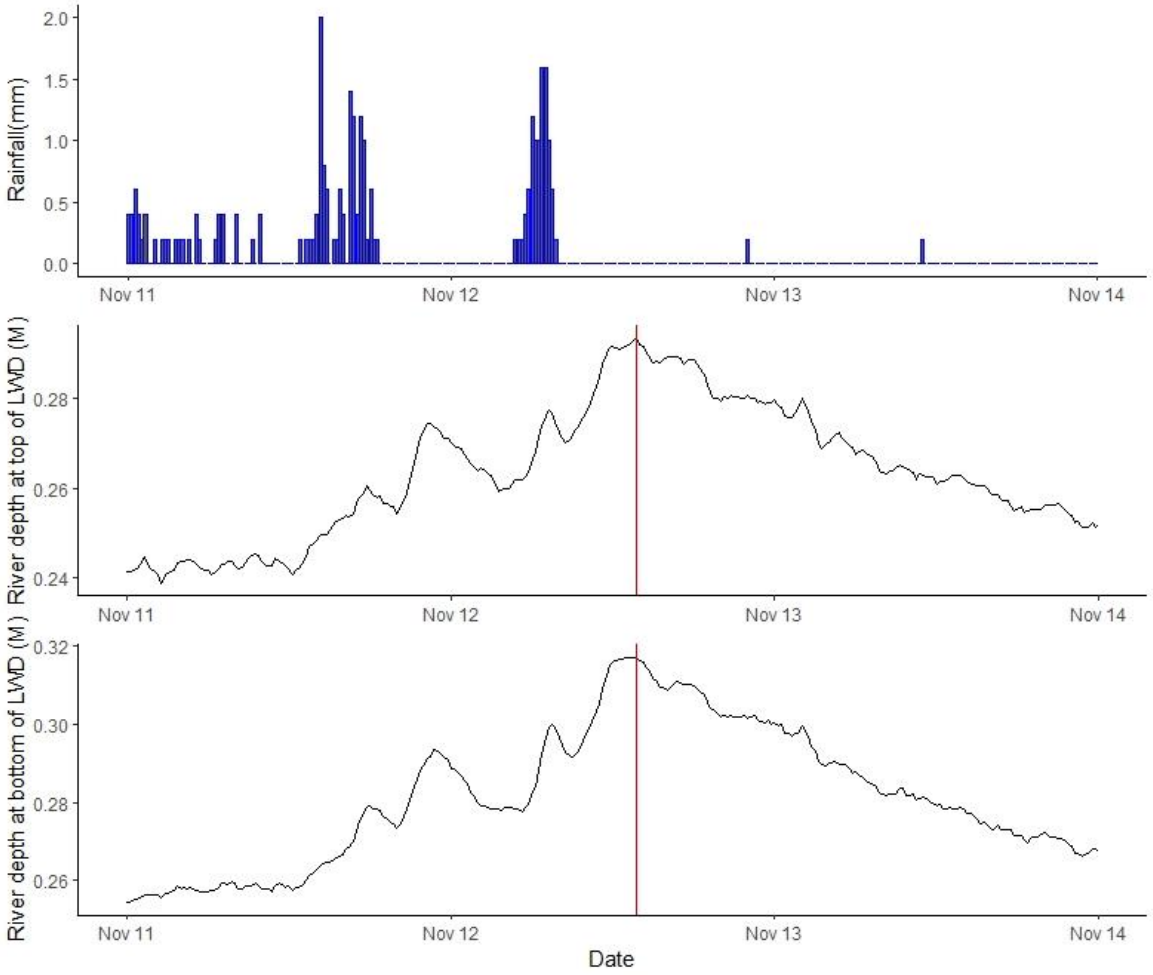


Figure B.15- A hydrograph of rainfall and river depth record during the 12th November 2019 group C event. The red line indicates the peak of the hydrograph.

Table B.3 - The table states the time and date the peak depth (m) recorded at the top and bottom of the leaky wood dam with a rolling average window of 3 and 5.The peak depth recorded is highlighted in blue.

| Date and Time (D/M/Y H:M) | Top of LWD (m) | Top of LWD Rolling average 3 (m) | Top of LWD Rolling average 5 (m) | Bottom of LWD (m) | Bottom of LWD Rolling average 3 (m) | Bottom of LWD Rolling average 5 (m) |
|---|---|---|---|---|---|---|
| 12/11/2019 13:15 | 0.293 | 0.2923333 | 0.2922 | 0.3163099 | 0.3174992 | 0.3168807 |
| 12/11/2019 13:45 | 0.294 | 0.2936667 | 0.2936 | 0.3164118 | 0.3168196 | 0.3170846 |
| 12/11/2019 14:00 | 0.294 | 0.2940000 | 0.2918 | 0.3161060 | 0.3170574 | 0.3160041 |
| 12/11/2019 14:15 | 0.294 | 0.2906667 | 0.2916 | 0.3186544 | 0.3152226 | 0.3156167 |

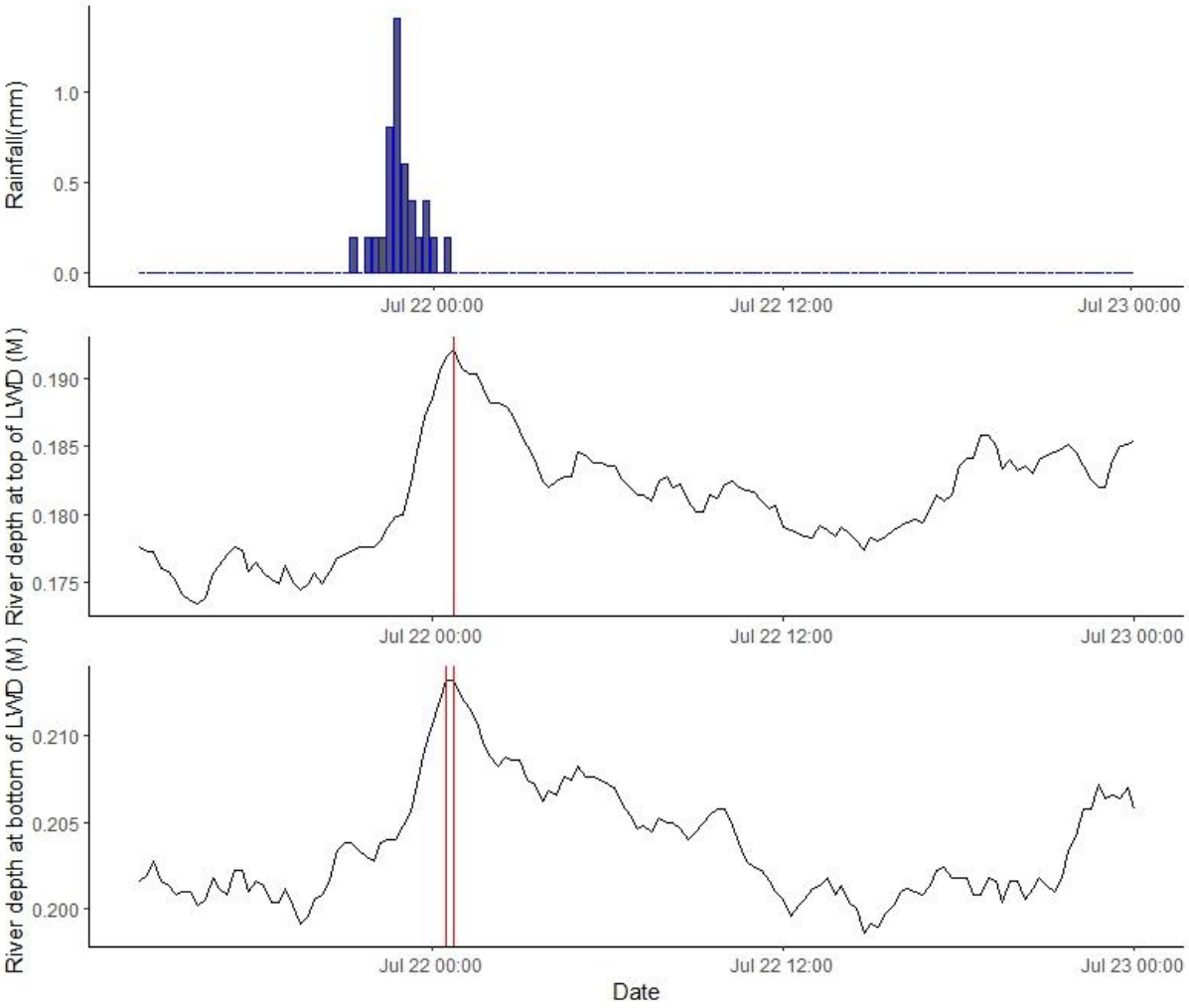


Figure B.15- A hydrograph of rainfall and river depth record during the 22 July 2019 group C event. The red line indicates the peak of the hydrograph.

Table B.4 - The table states the time and date the peak depth (m) recorded at the top and bottom of the leaky wood dam with a rolling average window of 3 and 5.The peak depth recorded is highlighted in blue.

| Date and Time (D/M/Y H:M) | Top of LWD (m) | Top of LWD Rolling average 3 (m) | Top of LWD Rolling average 5 (m) | Bottom of LWD (m) | Bottom of LWD Rolling average 3 (m) | Bottom of LWD Rolling average 5 (m) |
|---|---|---|---|---|---|---|
| 22/07/2019 0:15 | 0.195 | 0.1920000 | 0.1906 | 0.216 | 0.2136667 | 0.2120 |
| 22/07/2019 0:30 | 0.189 | 0.1910000 | 0.1916 | 0.210 | 0.2123333 | 0.2132 |
| 22/07/2019 0:45 | 0.189 | 0.1903333 | 0.1922 | 0.211 | 0.2116667 | 0.2132 |
| 22/07/2019 1:00 | 0.193 | 0.1923333 | 0.1908 | 0.214 | 0.2133333 | 0.2122 |
| 22/07/2019 1:15 | 0.195 | 0.1920000 | 0.1906 | 0.215 | 0.2133333 | 0.2120 |

Table B.5 - Results from Wilcoxon statistical test. Blue cells highlight significant results (<p0.05).

| **Variable name** | **Group types** | **Group types** | **Wilcoxon test** |
|---|---|---|---|
| Peak rainfall time to peak depth | A | B | 0.112 |
| | | C | 0.085 |
| | B | A | 0.112 |
| | | C | 0.033 |
| | C | A | 0.085 |
| | | B | 0.033 |
| Time taken between start of rainfall and start of event | A | B | 0.155 |
| | | C | 0.002 |
| | B | A | 0.155 |
| | | C | 0.069 |
| | C | A | 0.002 |
| | | B | 0.069 |

# Appendix C

## Responses to open questions

Table C.1 – Open question responses for question 1.1

How would you rate your current understanding of the impact of flooding?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I have volunteered with local flood groups | 4 | 10.53 | “I have been dealing with flooding in the Calder Valley for almost 40 years. 14 of which as a volunteer flood warden” |
| I have been flooded | 10 | 26.32 | “I’ve lived next to the River Calder and Rochdale Canal for over 25 years and my home had flooded numerous times” |
| I have an educational background in this subject | 4 | 10.53 | “Outdoor enthusiast with a degree in Civil Eng including hydrogeology and hydrology” |
| I work in this sector | 5 | 13.16 | “Work in Water Resources, involved in redesigning compensation flows at the Hebden Group reservoirs” |
| I have lived in areas which flood | 9 | 23.68 | “Living in the Calder Valley I am aware of the impact of flooding on local communities” |
| I have done my own research | 6 | 15.79 | “I listen to the news about it” |

Table C.2 – Open question responses for question 2.1

How would you rate your current understanding of flood management?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I have volunteered with local flood groups | 6 | 26.1% | “ I have volunteer with floody organisations” |
| I have previously had bad experience with local authorities | 3 | 13% | “The flood management authority does not provide regular accessible information / its lacks transparency” |
| I have an educational background in this subject and/or work in this sector | 5 | 21.7% | “I can see and can evidence the impact of flooding on the education of my pupils” |
| I have been flooded previously | 3 | 13% | “Council need to do more to raise awareness and fake proactive action to raise our confidence. We had 30 min of really heavy rain at the weekend and our moorings flooded and was horrendous. I've asked for help before (in Feb) and sooner and had zero response.” |
| I have done my own research | 9 | 39.1% | “We have kept updated with several local projects to mitigate local flooding, the alleviation works from Todmorden through to Mytholmroyd, Slow the Flow and others.” |

Table C.3 – Open question responses for question 3.a

Can you give examples of any flood management you are aware of in the area?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I have knowledge of hard engineering strategies | 14 | 48.3% | “Treesponsibility's contribution to 'Slow the Flow', attenuation of hydrograph.<br>Calderdale Borough Council's co-ordination of projects including persuading local landowners to join in schemes, building leaking dams, planting, discouraging drainage of moorland (natural bogs, which act as sponges).<br>Building of small terraces in woodlands and hillsides to encourage attenuation of soil, reducing soil erosion.<br>There are also the major civil engineering schemes in valley to reduce flooding of streets and properties eg Walden, Mytholmroyd, building up river banks, reducing vegetation in river course to encourage flows away from built-up area.<br>Hopefully there will be planning provisions to encourage permeable driveways, parking, gardening; use of water butts, small ponds, attenuation tanks on larger scales eg at Lidl, Todmorden.” |

| | | | |
|---|---|---|---|
| I have knowledge of NFM strategies | 19 | 65.5% | “The planting of a special moss on the moors to help hold water, the leaky dams being built above and in Hardcastle crags, the ‘ something’ ponds built on land above Todmorden and in Old town” |
| I have gained knowledge from local press and my own research | 5 | 17.2% | “Lot of press coverage locally raising awareness” |
| I have lived experience of dealing with flooding | 4 | 13.8% | “In the thick of it” |

Table C.4 – Open question responses for question 4.a.1

From the list below, how have you personally been affected by flooding? If you selected Other, please provide details:

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Education/work place floods | 1 | 50% | “My school floods” |
| Lived within a canal boat which is effected | 1 | 50% | “I used to live on a canal boat in the upper valley so my experience of flooding included securing boats opening sluice gates and lock gates slightly.” |
| My local area required help from external agencies | 1 | 50% | “Otherwise, I was affected due to the extreme flooding of the town which required support from |

| | | | |
|---|---|---|---|
| | | | external agencies for several weeks and several months before any sense of normality returned.” |

Table C.5 – Open question responses for question 5.a.1

Have you ever accessed any form of flood action or prevention within Calderdale? If you selected Other, please provide details:

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I have contacted the council | 2 | 33.3% | “I have attempted to Perdue a complaint against the council for increasing my risk of flood however they do not reply or respond which I’m told is their common practice.” |
| I have volunteered | 2 | 33.3% | “I was one of the founders of slow the flow Calderdale and served as chair for 18 months. I travelled to stroud to see what lessons could be learned.from their local nfm scheme.” |
| I have experience from work/education | 1 | 16.6% | “I used to manage 25 acre farm at Cragg Vale, investigating and implementing projects to reduce soil erosion, attenuate water on land reducing flows downstream. Worked with Treesponsibility and applied experience from work as Civil Engineer. |

| | | | |
|---|---|---|---|
| | | | Applied for post as N F Defence Coordinator at Calderdale Borough Council 3 years ago. Got an interview.” |
| I have local knowledge | 1 | 16.6% | “My local knowledge is the main source of information.” |
| I have used environment agency warning notifications | 1 | 16.6% | “EA warning notifications” |

Table C.6 – Open question responses for question 5.a.ii

What do you feel you have learnt and/or gained from this experience?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I have gained more flood knowledge | 2 | 15.4% | “I know where and when flooding is most likely.” |
| I feel forgotten/worries and/or I still get flooded | 4 | 23.1% | “Not a lot as still been flooded” |
| I have learnt about NFM | 3 | 23.1% | “NFM is an important part of the process.<br>Yorkshire Water's reservoirs in the Hebden Group can contribute up to 830 Ml of storage, Gorpley has an EA flood storage scheme around 100 Ml, plus...<br><br>Specific objectives: |

| | | | |
|---|---|---|---|
| | | | Ø 63.7 ha of woodland creation (102,245 trees) on Yorkshire Water land at Gorpley Reservoir<br><br>Ø 98 Turf Dams<br><br>Ø 106 Stone Dams<br><br>Ø 63 Willow Dams<br><br>Ø 322 Hazel / Brushwood Fascines<br><br>Ø 42,500 Sphagnum plugs planted for Peat bog margin repair<br><br>Ø 1000 Square metres Molinia diversification<br><br>Ø 1200 square metres Pond formation<br><br>Ø 27,400 square metres Heathland restoration” |
| I have a better awareness | 9 | 69.2% | “A decent understanding of why we suffer so much in the valley.” |
| I have a better understanding of the politics | 2 | 15.4% | “A wider understanding of how politics and funding impact on flood resilience and also how this impacts on local wildlife, flora and fauna. |

| | | | |
|---|---|---|---|
| | | | Also learnt about natural approaches to flood prevention and their impact.” |

Table C.7 – Open question responses for question 6.a.i

Where did you learn/ hear about natural flood management?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| From local flood groups/friends | 11 | 40.7% | “Online links from local flood groups to nfm information and articles.” |
| I have experienced it first hand | 2 | 7.4% | “If this is planting of trees etc, damming - intro of beavers etc,” |
| I have experienced from work | 5 | 18.5% | “Partly through Slow the Flow, and partly from an unorthodox angle (working with the Rural Payments Agency)” |
| I have done my own research | 2 | 7.4% | “Studies from Romania in rapid response catchment areas, The stroud valley nfm project and rspb managed moorlands in the lake district. Some trial and error in certain projects as well.” |
| I have learnt from social media/online | 4 | 14.8% | “Social media groups locally” |
| From Slow the Flow | 8 | 29.6% | “At various meetings came directly from Slow the Flow” |

Table C.8 – Open question responses for question 7.a

Can you explain your opinion of NFM as a flood management tool?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Doesn't know enough to have an opinion | 1 | 4% | "Don't know enough about it…" |
| Feels the NFM doesn't work | 1 | 4% | "Planting trees would never stop our school from flooding. The flood plain on the park has made flooding worse at our school" |
| Feels NFM should be used with several approaches | 4 | 16% | "No one action alone can reduce flood risks" |
| Prefers a more natural approach to flood management | 3 | 12% | "I like the sound of natural flood defences for the area." |
| Personally seen it work | 3 | 12% | "I like the sound of natural flood defences for the area." |
| Feels that NFM makes sense | 4 | 16% | "Self evident that every drop counts." |
| Feels that NFM is an upland measure | 4 | 16% | "The better we manage the flow of water before it gets into the river the less we will have to manage flooding in the river bottom" |

| | | | |
|---|---|---|---|
| NFM provides multiple benefits | 4 | 16% | “Natural methods should be better for the environment and wildlife” |
| Supports NFM | 22 | 88% | “Flattening the hydrograph by slowing the flow of water through the catchment is the only option to mitigate the flood risk that does not involve over-engineering in the valley bottom.” |
| NFM reduces the need for hard engineering/will help hard engineering be more effective | 5 | 20% | “I'm not convinced that concrete food defences do anything other than push the water further down the water course. NFM aids the landscape in managing the velocity of water and helps create natural habitats which has an ever increasing solution” |
| NFM is being mismanaged | 1 | 4% | “Some flooding is due to poor management from local councils and river authorities” |
| Wants more NFM introduced | 1 | 4% | “More is required” |

Table C.9 – Open question responses for question 8.a.i

What organisation and/or charities have you been involved with in Calderdale? If you selected Other, please specify:

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Set up and ran the flood relief hub in Mytholmroyd | 1 | 33.3% | |

| | | | |
|---|---|---|---|
| Rotary club or Halifax treeplanting | 1 | 33.3% | |
| Calderdale countryside ranger | 1 | 33.3% | |

Table C.10 – Open question responses for question 8.a.ii

What made you decide to volunteer?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Interested in nature | 3 | 30% | “I am passionate about enhancing nature, supporting reduction in soil erosion, encouraging economically viable land management projects which benefit general community eg reducing flooding.” |
| Wanted to give back to the community | 2 | 20% | “To give something back to the community of which I am a part” |
| Linked to work | 3 | 30% | “Work related, we have volunteering days.” |
| Felt they had to do something | 1 | 10% | “I could not sit around and do nothing….” |
| Felt they weren’t seeing results | 1 | 10% | “….I couldn't see a visible tangible response from local or national government so I did what I could.” |

| | | | |
|---|---|---|---|
| Wanted to protect against climate change | 1 | 10% | "…. increase resilience to climate change caused extreme weather events" |
| They had skills to help | 1 | 10% | "They had a gap and I had skills that would help fill the gap." |

Table C.11 – Open question responses for question 8.a.iii

What do you feel you have learnt and/or gained from this experience?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Have learnt something/ good experience | 6 | 100% | "Good experience" |
| Learnt about NFM | 3 | 50% | "Excitement to be involved with positive natural schemes. There are so many schemes to learn about and trial." |
| Learnt about the local area | 3 | 50% | "Volunteered many years ago but gained better understanding of things going in the area" |

Table C.12 – Open question responses for question 8.a.iv

Have you noticed any benefits through volunteering? If so, please provide details

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Connection to community | 4 | 80% | "I feel more connected to my community." |

| | | | |
|---|---|---|---|
| Meet new/likeminded people | 2 | 40% | “There is an excitement and enthusiasm which volunteers have, bring new ideas and fresh creativity.” |
| Support | 1 | 20% | “A ‘shared’ experience of flooding.” |

Table C.13 – Open question responses for question 8.a.v

How do you feel your mental health has been impacted?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Positive effect | 6 | 100% | “Positively” |
| Greater connection to their local area | 2 | 33.3% | “It's helped me see where I live as a something more than just a place I come back to after work, I now have a connection.” |

Table C.14 – Open question responses for question 8.a.vi.a

Can you explain the above feelings about the statement 'I feel more connected to my local environment when I volunteer to implement natural flood management’? Please explain below.

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Appreciate the environment more | 2 | 33.3% | “General improvement” |

| | | | |
|---|---|---|---|
| Greater connection with the community | 1 | 16.6% | “Stimulated and feeling fulfilled on making meaningful long lasting contributions to enhancing our landscape and protecting communities.” |
| Lack of opportunities locally | 1 | 16.6% | “By local if you mean Yorkshire. Lack of opportunities locally.” |
| Feels NFM is an attractive option | 1 | 16.6% | “I think that NFM has a PR advantage through making people feel more involved (whether or not any single intervention is very effective) |

Table C.15 – Open question responses for question 8.a.vii.a

What were the reasons why you visited NFM interventions in your own time?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Wanted to see if they were working | 5 | 62.5% | “I wanted to see how they were developing, and show off my work...” |
| To observe nature | 2 | 25% | “I am very interested in the schemes, stimulating new creative ideas. It is uplifting to know the local communities have been involved, including kids.<br>I love watching and observing nature, there's so much to learn.” |
| For scientific purposes | 2 | 25% | “Monitoring visits” |

Table C.16 – Open question responses for question 8.b

In the future, would you be interested in volunteering for NFM projects? Please explain why.

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| No | 9 | 34.6% | “No. I have a disabled child and I choose to volunteer for organisations that support people with a disability” |
| Plans to in the future | 8 | 30.8% | “Yes. I am retired and have the time. I think it is an important need.” |
| Possibly would be | 4 | 15.4% | “Possibly - I organise a community river clean annually” |
| Physically unable to volunteer | 4 | 15.4% | “Just had hip and knee replacement so not for me.” |
| Doesn’t have time to volunteer | 8 | 30.8% | “I simply do not have the time as I work full time & have other caring responsibilities” |
| Feels the NFM could create more flooding | 1 | 3.8% | “No.<br>Slowing flow can actually add to flooding issues” |

Table C.17 – Open question responses for question 9.a

How would you rate your awareness of NFM projects that are happening in Calderdale?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Heard about NFM from Slow the Flow | 3 | 20% | “I know some members of Slow the Flow & flood wardens” |
| I have heard about it from local press | 4 | 26.6% | “I only know what I hear on the news and what I see driving through flood affected areas” |
| I have learnt about NFM from work/as a trustee | 3 | 20% | “I am the lead flood warden for Todmorden so have to keep up with all of what is happening to reduce the flood risk of the valley.” |
| I have had access to very little information | 1 | 6.6% | “There is not much open information & the council offer we zero support to those living higher than the valley bottom” |
| I have learnt about NFM from Facebook | 1 | 6.6% | “I see the Slow the Flow guys on FB, saw John Richardson was balsam bashing in Hardcastle Crags.” |
| I have interest in local projects | 4 | 26.6% | “I was very interested as manager of a small farm in Cragg Vale in how to reduce soil erosion due to storms, how to reduce/prevent flooding of farm buildings, how to attenuate flows on farm to reduce flooding in lower valley Contacted Treesponsibility and began to learn a lot more about local schemes.” |

Table C.20 – Open question responses for question 10.a

How do you feel about the statement ‘I believe NFM has reduced flood risk in Calderdale'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| I don’t have enough evidence/knowledge | 8 | 26.2% | “I can’t see any evidence of it being used or it having an impact on the area I live in” |
| Have seen NFM work | 8 | 26.2% | “Hebden water has not reacted as much as it has in previous similar rainfall events. I'm putting this down to the hundreds of leaky Woody debris dams and attenuation ponds in hardcastle crags” |
| Too early to say if NFM works and/or more need to be done | 9 | 30% | “I think it WILL, but whether it has yet on any major scale is too early to say” |
| Feels that NFM doesn’t work | 2 | 6.6% | “Because it’s getting worse” |
| Understands how NFM works | 2 | 6.6% | “I think I understand the need to delay rainwater reaching the rivers (without risk to life or property)” |
| Feels there are issues with hard engineering | 1 | 3.3% | “A very large percentage of the street drains are simply blocked up and poorly maintained. One observes water simply rushing |

| | | | |
|---|---|---|---|
| | | | over them and causing flooding.” |
| Feels there has been significant implementation of NFM | 5 | 16.6% | “All those leaky dams and tree planting lop the peak off any flood response.” |

Table C.21 – Open question responses for question 11.a

How do you feel about the statement ‘I wish to be more involved with the implementation of NFM' (e.g. planning, designing and implementing)?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Would like to be more involved | 5 | 33.3% | “I feel I have a lot to contribute with my passion about NFM and experience.” |
| Would prefer to leave it to the experts | 2 | 13.3% | “Well, i'd love to be involved, but planning and designing should be left to people with expertise. There are a lot of strong opinions around here about flood management, many of them total rubbish...” |
| They are unable to be more involved | 4 | 26.7% | “See above plus age (86)” |
| Wish more involvement from local government and council | 2 | 13.3% | “Calderdale Council now need to be ambitious and take this forward with a large scale plan for nfm implementation. They have been sat on nfm funding for years with no plan on how to use |

| | | | |
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| | | | it. They have had 4 nfm project officers with 0 nfm projects.” |
| They wish to help protect more properties | 1 | 6.7% | “As many properties in my area have been effected” |
| Feels NFM will not resolve flooding | 1 | 6.7% | “I do not believe slow the flow will solve the problem.” |

Table C.22 – Open question responses for question 12.a

How do you feel about the statement 'I believe that NFM measures are an effective tool at reducing flood risk'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Feels NFM works at reducing flooding | 4 | 30.8% | “Common sense to me and there are major study cases across UK which support the efficiency of NFM” |
| Feels NFM needs more time to start working at reducing flooding | 2 | 15.4% | “It is its early days of action so will have to see over many years how successful it becomes.” |
| Feels they do not know enough about NFM to have an opinion | 2 | 15.4% | “Don’t know enough to comment” |
| Feels more evidence is needed to have an opinion | 1 | 7.7% | “I understand more evidence is required to understand impacts in medium/large catchments, improve understanding of costs/benefits and take longer term maintenance into account” |

| | | | |
|---|---|---|---|
| Feels that Calderdale needs many more projects to see an effect | 3 | 23.1% | “Need several projects to work together” |

Table C.23 – Open question responses for question 13.a

How do you feel about the statement 'I feel NFM should be used with several other measures to reduce flood risk'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Agree NFM should be part of several flood management strategies used. | 12 | 63.2% | “This is probably true as most serious problems require a multi-faceted approach to be fully effective” |
| Disagreed and felt NFM should be used exclusively | 2 | 10.5% | “I am sceptical of the effect of other measures. Man made flood prevention (eg in Todmorden or Mytholmroyd) seems to me to increase the risk of flooding downstream (eg in Elland and Brighouse)” |
| Feels that floodplains should not be developed | 4 | 21.1% | “Building on flood plains removes opportunities for NFM. Stop building on sites that have previously been flooded.” |
| Supports continuing dredging of rivers | 2 | 10.5% | “Dredging the drainage channels on farmland/ country lanes rarely happens now as many farms are |

| | | | |
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| | | | now just residential (speaking from personal experience as I lived on a farm in Mytholmroyd all my childhood and my Dad regularly checked ours) . Dredging / clearing vegetation from the river bed doesn't happen as regularly. People are allowed to build on land which in turn means the old routes for the water to go/ drain are diverted, the local drains are not always increased despite many new houses feeding into them" |
| Doesn't know enough about the topic | 1 | 5.3% | "I don't know enough about it to form an educated opinion" |
| Feels better monitoring and maintenance of existing features should be used | 1 | 5.3% | "As mentioned previously, good monitoring and maintenance of existing drains" |

Table C.24 – Open question responses for question 14.a

How do you feel about the statement 'I believe NFM is improving my local environment. (e.g. nature, ecosystems and wildlife) '?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Agrees that NFM improves local environments | 9 | 75% | “There are more trees, properly managed, less soul erosion, encouragement of natural wild flowers, inviting insects, birds, small mammals etc” |
| More time/ more NFM is required to form an opinion | 3 | 25% | “So far, interventions have mostly been quite small, so the ecological impact would be small too. More could be done.” |
| Doesn’t know | 1 | 8.3% | “I don’t know much about it” |
| Feels NFM has impacts for landowners | 1 | 8.3% | “Depends on outlook. Prevention of existing moorland management from city based people forming pressure groups on landowners is not acceptable.” |

Table C.25 – Open question responses for question 15.a

How do you feel about the statement ‘I believe I have personally benefited from the implementation of NFM’?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Doesn’t know enough | 2 | 20% | “I don’t know much about it” |
| Feels they have seen benefits | 4 | 40% | “Planting trees with Treesponsibility on small farm saved soul erosion, retained soil for growth of natural grasses, wild flowers, saw more insects, birds |

| | | | |
|---|---|---|---|
| | | | etc within 2 years land was improved. |
| Found personal benefits | 1 | 10% | “good exercise and new friends!” |
| Still experiences flooding | 1 | 10% | “Still been flooded” |
| Feels that some projects can create secondary problems | 1 | 10% | “Some projects lead to other problems like moorland fires.” |
| Has never been flooded previously | 1 | 10% | “I don't live in an area that floods” |

Table C.26 – Open question responses for question 16.a

How do you feel about the statement ‘I believe my community has benefited from the implementation of NFM’ (e.g. community spirit, improving wellbeing, community engagement)?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Doesn’t know/ Hasn’t experienced flooding | 5 | 33.3% | “I personally have no experience or evidence to comment” |
| NFM is not effective yet | 3 | 20% | “Not been in operation long enough to find out yet” |
| Felt that they were unable to make a decision | 2 | 13.3% | “Between "engagement" and "reducing flood risk", it's hard to disentangle cause from effect.” |
| Felt there was positive benefits | 4 | 26.7% | “I think that it has helped people to take back some control of the |

| | | | |
|---|---|---|---|
| | | | potential flood risk locally - empowered people to act positively to manage the flood risk of their own homes and the wider town. This is powerful as flooding has also had big impact on mental health in the valley and being able to do something proactive to manage this I think is very empowering for people” |

Table C.27 – Open question responses for question 17.a

How do you feel about the statement 'I believe that developing my awareness around NFM has had an impact on my mental health'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Felt there was a positive impact | 4 | 40% | “Volunteering is important. Learning new skills keeps your mind active and focused on the present.<br><br>Plus it is a positive act to help reduce the risk of suffering and damage to other people's property and livelihoods” |
| Reported that they had no metal health issues | 2 | 20% | “I have no mental health issues.” |
| Have little knowledge/awareness of the impact | 2 | 20% | “I have little awareness” |

| | | | |
|---|---|---|---|
| Felt that it was better than doing nothing | 1 | 10% | “Doing something positive will always have a more positive impact than doing nothing.” |
| Had no emotions linked to flooding | 1 | 10% | “Personally I am quite blasé about flooding. Have been flooded before (both in Calderdale and in Belgium) and there's no anxiety over it, no emotion, it's a strictly practical matter of work and cost and risk.” |
| Feels the government/landowners hold responsibility | 1 | 10% | “Why can’t the government do it. Why are the rich land owners keeping their land for shooting? It’s ridiculous.” |

Table C.28 – Open question responses for question 18.a

How do you feel about the statement 'I believe NFM has made me more resilient to the impact of flooding’?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Feels it has a positive impact | 3 | 27.3% | “Practical skills or help manage the impact of flooding has helped us become resilient as local community” |

| | | | |
|---|---|---|---|
| Has never been flooded previously | 3 | 27.3% | “As I am not directly affected by flooding I am unable to give a good answer.” |
| Doesn’t know | 2 | 18.2% | “I have little awareness” |
| Still floods | 1 | 9.1% | “We still flooded and have many near misses m lots of hot spot areas ignored and basics like drains blocked despite forecasts.” |
| Feels NFM has had no impact on personal resilience | 1 | 9.1% | “I don't think it has affected my personal resilience, though others may feel differently.” |
| Feels more needs to be done to see an impact | 1 | 9.1% | “There is so much further to go and more to be done.<br>Farmers can completely rethink their practices to be more productive on their land, to benefit their communities.<br>Sepp Holzer shows us the way in his permaculture farming practices 2000m altitude in Austrian Alps.<br>We can create micro-climates growing fruits and produce in the most inhospitable landscapes.<br>Practices which involve NFM, fish farming, local food production, local employment” |

Table C.29 – Open question responses for question 18.b

How do you feel about the statement 'I believe NFM has made me more resilient in recovering from flooding’?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Not been flooded previously | 4 | 50% | “My location (-------) is not prone to flooding or affected by any measures taken |
| Feels NFM has had no effect | 2 | 25% | “I don't think it has affected my personal resilience, though others may feel differently.” |
| Still floods | 2 | 25% | “No idea what you've done sorry and seen no benefit. Try watching the sky anxiously for hours like we do wondering if this is the one or try getting back when you work out of the area when trains stop at the sniff of flooding being possible and no bus service is on and you have to share a taxi with strangers that take you via unknown territory” |
| Feels more needs to be done | 1 | 12.5% | “Our cellar still floods. There's hope but there's a long way to go.<br>No room for complacency or backing off the schemes!” |
| Feels they have gained experience | 1 | 12.5% | “After 4 floods anyone would have gained experience.<br>Just need grants for flood gates that work.” |

Table C.30 – Open question responses for question 19.a

How do you feel about the statement 'I believe NFM has made my community more resilient to the impact of flooding'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Feels it has had a positive impact | 3 | 33.3% | "It is a long process but it has started and is showing encouraging signs." |
| Not been flooded | 2 | 22.2% | "The answer is relevant to areas which emply this and in which I previously lived" |
| Unaware of any impacts | 2 | 22.2% | "Unaware of any impact" |
| Felt it had made flooding elsewhere worse | 1 | 11.1% | "Just pushing the flooding down the valley" |
| Feel that people only gained awareness of the impacts when they became more involved | 1 | 11.1% | "Many locals do not know of schemes. Only those who wish to be involved and informed." |

Table C.31 – Open question responses for question 19.b.

How do you feel about the statement 'I believe NFM has made my community more resilient in recovering from flooding'?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Not previously been flooded so felt no impact | 3 | 42.9% | |
| Feels they are not aware of any impacts | 2 | 28.6% | “My neighbours in valley bottom in Todmorden complain about flooding. They are not aware of NFM schemes. They want to know why the drains don't work.<br>How do the general local population get to hear about NFM schemes, when they are not informed.<br>Are local schools involved with schemes? Are their parents invited?<br>Covid allowing of course?!” |
| Positive impacts | 1 | 14.3% | |
| Feels that NFM is one of several measures | 1 | 14.3% | “One of several important measures” |

Table C.32 – Open question responses for question 20.a

How do you feel about the statement 'I have confidence in the charities, local government, private companies and government agencies to manage NFM within Calderdale’?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Government and council should | 11 | 45.9% | “This should not be up to volunteers. This requires MPs to |

| | | | |
|---|---|---|---|
| have more responsibility | | | take accountability for constituents” |
| Feels that more needs to be done/ they haven’t had enough time to show an effect | 6 | 25% | “The scale needs to be increased and this must come from Government policy.” |
| Feels that charities are trusted more | 5 | 20.8% | “Local charities and groups have been the only ones delivering nfm in Calderdale. I stepped down as chair as the group felt it was not the time to start pushing local government to take the lead in nfm. I am of the opinion that local groups have done all they can with their limited resources and it's now time for local authorities to step up as the biggest landowners and start taking action, not just turning up for day trips out and photo opps.” |
| Feels there should be more restrictions on landowners | 5 | 20.8% | “Most organisations are capable enough, but the one organisation that could make the biggest difference - the RPA, which dominates the income of landowners and has the power to change these land-use subsidies to incentivise flood risk reduction - is nowhere to be seen.” |
| Feels they need more information to have an opinion | 2 | 8.3% | “Not sure how it all fits together and whether there is sufficient funding in place.” |

| | | | |
|---|---|---|---|
| Feels there should be more funding for NFM | 5 | 20.8% | “Grants are limited. Sometimes a subsequent flood requires more support but this can be refused.” |
| Feels they have done a good job | 1 | 4.2% | “They have done well over the last 5 years” |

Table C.33 – Open question responses for question 21.a

What do you feel is the government agency's (eg. Environment Agency) role in NFM projects?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Funding | 22 | 51.2% | “To provide funding” |
| Project management | 17 | 39.5% | “Funding & project management” |
| Guidance | 9 | 20.9% | “Funding, higher level guidance, providing a regulatory framework, and - in the case of the RPA - it *should* be providing powerful incentives to owners of land & watercourses through their existing subsidy schemes.” |
| Should be leading projects | 7 | 16.7% | “Driving it forward, using best practice, pulling parties together.” |
| Planning | 6 | 14.3% | “To be stricter with planning/ development regulations and make sure all new developments include the effect their building will have on local flooding and how they will take measures to not create added flooding” |

| | | | |
|---|---|---|---|
| Land owner engagement | 3 | 7.1% | “They should be financially supporting projects and also working on measures such as banning burning on the tops that have a huge knock-on effect further down the valley.” |
| Shouldn’t be involved | 3 | 7.1% | “If it can be made worse, they'll find a way to make this happen” |
| Monitoring | 2 | 9.5% | “Big stuff - modelling, simulation, research funding, monitoring, coordination across catchments” |

Table C.34 – Open question responses for question 21.b

What do you feel is the local government's (eg. local councils) role in NFM projects?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Funding/making projects cost effective | 16 | 37.2% | “Decide how funding is distributed & once and for all for Todmorden to be put at the top of priority list instead of always at the bottom” |
| Local level guidance and support | 13 | 30.2% | “Local level understanding of need” |
| Communication of projects for stakeholders and residents | 9 | 20.9% | “Communication and consultation” |
| Implementation of NFM | 7 | 16.3% | “Installation and management” |

| | | | |
|---|---|---|---|
| Management of projects | 7 | 16.3% | “They should co-ordinate projects, ensuring communication, education, managing government funding specifically for NFM” |
| Facilitation | 6 | 14% | “Integration into local built environment, planning controls, education, outreach, leading by example” |
| Education of NFM | 5 | 11.6% | “Support however they are able. They may not have the finances to help, but they can help with spreading the word, education, publicly supporting the initiatives in other ways.” |
| Landowner engagement | 4 | 9.3% | “Much more proactive with landowners.” |
| No involved | 5 | 11.6% | “Calderdale & it’s officers are not fit for purpose - the have increased the flow & risk to my property they are incompetent & should not be allowed any role or squander any further public money” |
| Planning | 4 | 9.3% | “Management, design and planning” |
| More involved | 3 | 7% | “They should be involved” |
| Upkeep of NFM measures | 3 | 7% | “Safeguard the interests of its residents, communicate and keep road gullys clear which they never do and investigate complaints of blocked drains on the highway which they ignore. Still waiting for |

| | | | |
|---|---|---|---|
| | | | a response to one I reported on February and no doubt covid will be used as an excuse for incompetence” |
| Developing regulation | 1 | 2.3% | “As above , but to approach local landowners regarding protecting previously flooded properties , rather than the onus being on the householder” |
| Not sure | 1 | 2.3% | “Not sure” |

Table C.35 – Open question responses for question 21.c

What do you feel is the role of national charities (eg. National Trust) in NFM projects?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Implementation of NFM on there land | 16 | 38.1% | “Using land to benefit projects and prioritise flood measures” |
| Education of NFM | 11 | 26.2% | “Landowner responsibility, knowledge and reach to educate and promote NFM.” |
| Helping other landowners | 4 | 9.5% | “Implementing them on their land and being involved with local land owners to have schemes that work together.” |
| No role | 5 | 11.9% | “Not aware they have a role (save to the extent they are landowners)” |

| | | | |
|---|---|---|---|
| Lobbying/ Giving advice to government | 6 | 14.3% | “Support and implement on own land, lobby nationally, act as champion for approach” |
| Helping contribute/ doing more | 3 | 7.1% | “Where they can but not the main stakeholder” |
| Monitoring NFM | 2 | 4.8% | “To help develop & build data” |
| Supporting local residents | 1 | 2.4% | “Support residents and deal with after flood issues” |
| Not sure | 1 | 2.4% | “Not sure” |
| Managing resources | 1 | 2.4% | “Managing their resources” |

Table C.36 – Open question responses for question 21.d

What do you feel is the role of local community groups (eg. Slow The Flow) in NFM projects?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Education on NFM | 10 | 23.3% | “Education to the public, helping to maintain NFM projects” |
| Implementation of NFM | 14 | 33.3% | “Assist with implementing” |
| Community engagement | 8 | 19% | “Raising awareness, community engagement” |
| Take the lead on NFM | 7 | 16.7% | “Take ownership” |
| Advisory / planning NFM | 7 | 16.7% | “Consultants or provider if they have the funding” |

| | | | |
|---|---|---|---|
| Work with other agencies | 6 | 14.3% | “Work with others to sustain” |
| Lobby the government | 5 | 11.9% | “Make local views known” |
| Data collection/ monitoring NFM | 4 | 9.5% | “Design and overall monitoring group” |
| Talking to landowners | 3 | 7.1% | “Volunteer workforce and persuasion of local landowners to co-operate” |
| Designing NFM | 2 | 4.8% | “Get locals involved in planting/coordinating design where this is relevant” |
| Leave NFM to other agencies | 2 | 4.8% | “The local groups can encourage community involvement to create enthusiasm, interest, education, and encourage locally specific knowledge and creative ideas. But larger NFM projects require professional technical expertise eg large lakes on moorlands, education of landowners of large estates and farms.” |
| No role | 2 | 4.8% | “None” |

Table C.37 – Open question responses for question 22.a

Can you list some of the effects that you know about?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Biodiversity | 12 | 48% | “Improved biodiversity, returning wildlife and the subsequent benefits of this” |

| | | | |
|---|---|---|---|
| Tree planting | 7 | 28% | “More woodland, wildlife, wetland areas, less concrete etc in unnatural remedies, community spirit, more ecosystems” |
| Habitat creation | 7 | 28% | “Environmental and habitat improvement.<br><br>Tree planting can reduce reservoir yield and increase DOC and THM formation” |
| Wildlife | 7 | 28% | “Benefit wildlife” |
| Reduces erosion | 5 | 20% | “Less soil erosion in the higher reaches and catchment areas” |
| Water quality | 2 | 8% | “Woodland management<br>Improving water quality (sediment control)<br>Biodiversity (improving water quality, controlling non-native species, etc)” |
| Negative impacts | 2 | 8% | “NFM is not just a box to be ticked and walked away from.<br>We are only so far looking at tip of the iceberg schemes so far.<br>We cannot underestimate the full potential and scope for major changes in attitudes towards landownership, responsibility and management.<br>Small local voluntary groups can do the small stuff, significant in education and community building, feel good factors, but the Environment Agency and |

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|---|---|---|---|
| | | | government need to wake up to the full implications of the benefits of sustainable, permaculture practices across the nation.” |
| Moved water elsewhere | 1 | 4% | “It could move the water elsewhere” |

Table C.38 – Open question responses for question 23.a

Can you please explain why you have chosen this order of importance?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Didn’t agree with the ranked question | 6 | 33.3% | “I would have liked to choose more but your system will not allow it and I think the majority of your questions deserve the lions share. Most deserve to be in column number 1 as they are all equally important.” |
| All important | 5 | 27.8% | “Sorry I don’t think this ranking question is helpful. These things are all important- the NFM is an good approach precisely because it has multiple positive outcomes” |
| Flood risk is most important | 5 | 27.8% | “Reducing the flood risk must take priority” |
| Environmental/ Ecosystem benefits are important | 2 | 11.1% | “Whilst all of these is important, a natural resilient ecosystem covers a lot of these others. We need to set in place long term, nature schemes, which |

| | | | |
|---|---|---|---|
| | | | require harmonious maintenance.<br>Community spirit is very important, but not a box to tick, it comes from long-term sustainable practices.” |
| Community spirit is important | 2 | 11.1% | “Flooding causes huge destruction for people but also animals habitats and if we can help to prevent it then we should. I feel that community spirit can take place in many forms.” |
| People are more important than nature | 1 | 5.6% | “Sustainable change for the benefit of people followed by nature and then people’s need for fulfilment” |
| Climate is the most important | 1 | 5.6% | “Climate above all. Everything else derives from a survivable environment.” |

Table C.39 – Open question responses for question 24

Is there any other comment you wish to make in relation to NFM which has not been covered in this questionnaire?

| Category selected | Number of responses | Percentage of responses | Noted important quotes |
|---|---|---|---|
| Getting greater landowners involvement is vital | 3 | 75% | “We can do all we want with small landowners on the valley sides, but until the big landowners on the moor tops (AKA the grouse |

| | | | |
|---|---|---|---|
| | | | moors) are brought onboard, we're ignoring the largest area to be improved. Yorkshire water's project at Gorpley is a great example.” |
| Stronger protection for existing NFM | 1 | 25% | “Stronger protection for existing NFM” |
| Feels more SUDS design should be incorporated within new development | 1 | 25% | “I'd like to know why local new housing estate has solid driveways.<br>Is flooding department not co-ordinating with planning department?<br><br>Can landowners be encouraged by legislation to lease or sell land for allotments? These are naturally more retentive of flow than empty fields.<br>Are sheep in grass fields so vital to our economy?<br>Can we investigate and implement permaculture and wilding into NFM?” |

Demographic information

Table C.40 – Age of participants

| Age Range | Number of participants |
|---|---|
| 18 - 25 | 1 |
| 26 - 35 | 7 |
| 36 - 45 | 9 |

| | |
|---|---|
| 46 - 55 | 12 |
| 56 - 65 | 14 |
| 66 -75 | 7 |
| 76 - 85 | 0 |
| 86+ | 1 |

C.41 Gender of participants

| Gender | Number of participants |
|---|---|
| Female | 27 |
| Male | 21 |
| Transgender Female | 0 |
| Transgender Male | 0 |
| Gender Variant/Non-Conforming | 1 |
| Not listed | 1 |
| Prefer not to say | 1 |

C.42 Employment status of participants

| Employment status | Number of participants |
|---|---|
| Employed (full time) | 28 |
| Employed (part time) | 8 |
| Unemployed | 0 |
| Student | 0 |
| Retired | 13 |
| Self-Employed | 5 |
| Unable to work | 2 |
| Would prefer no to say | 0 |

C.43 What is/was participant occuptation

| Occupation | Number of participants |
|---|---|
| Public sector - Environment | 2 |

| | |
|---|---|
| Public sector- Local Government | 11 |
| Private sector - Environment | 4 |
| Private sector - Other | 14 |
| Charity sector - Environment | 0 |
| Charity sector - Other | 1 |
| Academic | 5 |
| Farming | 1 |
| Other | 10 |

C.44 Level of education of participants

| Employment | Number of participants |
|---|---|
| GCSE/O level or equivalent | 1 |
| A level or equivalent | 8 |
| Bachelor's degree or equivalent (eg. BA, BSc) | 19 |
| Master's degree or equivalent (eg. MA, MSc, Med) | 17 |
| Doctorate or equivalent (eg. PhD, EdD) | 4 |
| Would prefer not to say/NA | 1 |
| Other (please specify) | 1 |

C.45 Town in which participant reside in

| Location | Number of participants |
|---|---|
| Hebden Bridge | 17 |
| Mytholmroyd | 3 |
| Todmorden | 15 |
| Other | 21 |

# Appendix D

Trail Camera footage

Table D.1 - Trail camera footage collected at the top and the bottom of the reach before and after an event

| Type of event | Before event top of reach | After event top of reach |
|---|---|---|
| Group A NFM had an effect - Delay in peak |   |   |

| | | |
|---|---|---|
| Group B Event in which NFM had ‘no effect’ |  |  |

| | | |
|---|---|---|
| Group C Peaked at bottom before top |  |  |